

PCT

INTERNATIONAL SEARCH REPORT

(PCT Article 18 and Rules 43 and 44)

Applicant's or agent's file reference P23293	FOR FURTHER ACTION see Notification of Transmittal of International Search Report (Form PCT/ISA/220) as well as, where applicable, item 5 below.	
International application No. PCT/US 99/ 08572	International filing date (day/month/year) 19/04/1999	(Earliest) Priority Date (day/month/year) 17/04/1998
Applicant TURBOSAT TECHNOLOGY, INC. et al.		

This International Search Report has been prepared by this International Searching Authority and is transmitted to the applicant according to Article 18. A copy is being transmitted to the International Bureau.

This International Search Report consists of a total of 3 sheets.

☒ It is also accompanied by a copy of each prior art document cited in this report.

1. Basis of the report

- a. With regard to the language, the international search was carried out on the basis of the international application in the language in which it was filed, unless otherwise indicated under this item.

☐ the international search was carried out on the basis of a translation of the international application furnished to this Authority (Rule 23.1(b)).

- b. With regard to any nucleotide and/or amino acid sequence disclosed in the international application, the international search was carried out on the basis of the sequence listing:

☐ contained in the international application in written form.

☐ filed together with the international application in computer readable form.

☐ furnished subsequently to this Authority in written form.

☐ furnished subsequently to this Authority in computer readable form.

☐ the statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.

☐ the statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished.

2. ☐ Certain claims were found unsearchable (See Box I).

3. ☐ Unity of invention is lacking (see Box II).

4. With regard to the title,

☐ the text is approved as submitted by the applicant.

☒ the text has been established by this Authority to read as follows:

SPACECRAFT SHADING DEVICE

5. With regard to the abstract,

☒ the text is approved as submitted by the applicant.

☐ the text has been established, according to Rule 38.2(b), by this Authority as it appears in Box III. The applicant may, within one month from the date of mailing of this international search report, submit comments to this Authority.

6. The figure of the drawings to be published with the abstract is Figure No.

☒ as suggested by the applicant.

☐ because the applicant failed to suggest a figure.

☐ because this figure better characterizes the invention.

5

☐ None of the figures.

INTERNATIONAL SEARCH REPORT

International Application No

PCT/US 99/08572

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 B64G1/50

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 6 B64G

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
P, X	EP 0 887 260 A (AEROSPATIALE) 30 December 1998 (1998-12-30) the whole document ---	1-5, 7-12, 17-20, 26-28, 30-32
X	EP 0 447 049 A (MARCONI GEC LTD) 18 September 1991 (1991-09-18) the whole document ---	1-12, 17-20, 25-28, 30 31, 32
A		
X	EP 0 271 370 A (CENTRE NAT ETD SPATIALES) 15 June 1988 (1988-06-15) the whole document ---	1-5, 7, 12, 17, 26-28, 30
	--- -/--	

☒ Further documents are listed in the continuation of box C.☒ Patent family members are listed in annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

25 February 2000

Date of mailing of the international search report

15/03/2000

Name and mailing address of the ISA

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,
Fax: (+31-70) 340-3016

Authorized officer

Calvo de Nõ, R

INTERNATIONAL SEARCH REPORT

International Application No

PCT/US 99/08572

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X A	US 5 527 001 A (STUART JAMES R) 18 June 1996 (1996-06-18) abstract column 6, line 17 - line 55 -----	1, 2 3, 6, 8-13, 15, 17-21, 23
A	US 4 725 023 A (SHIKI HARUO) 16 February 1988 (1988-02-16) cited in the application column 1, line 33 - line 52 column 3, line 15 - line 40 -----	1-3, 9, 12, 17-19
A	FORTESCUE P W, STARK J P W: "Spacecraft Systems Engineering" 1990, WILEY & SONS, CHICHESTER, UK XP002131587 195570 page 280, paragraph 3 -page 284, paragraph 2 table 12.5 page 288, paragraph 3 -page 291, paragraph 2 page 291, paragraph 5 -page 292, paragraph 4 page 293, paragraph 5 - paragraph 7 -----	1-5, 7

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PCT/US 99/08572

Patent document cited in search report		Publication date	Patent family member(s)		Publication date
EP 0887260	A	30-12-1998	FR 2765190 A		31-12-1998
			JP 11059600 A		02-03-1999
EP 0447049	A	18-09-1991	JP 4218497 A		10-08-1992
EP 0271370	A	15-06-1988	FR 2605287 A		22-04-1988
			AT 53360 T		15-06-1990
			GR 3000547 T		31-07-1991
US 5527001	A	18-06-1996	AU 7139794 A		03-01-1995
			WO 9429927 A		22-12-1994
US 4725023	A	16-02-1988	JP 1625104 C		18-11-1991
			JP 2039440 B		05-09-1990
			JP 60022600 A		05-02-1985
			CA 1262890 A		14-11-1989
			EP 0132768 A		13-02-1985

REC'D 02 OCT 2000

WIPO

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INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Article 36 and Rule 70)

Applicant's or agent's file reference ./.	FOR FURTHER ACTION See Notification of Transmittal of International Preliminary Examination Report (Form PCT/IPEA/416)	
International application No. PCT/US99/08572	International filing date (day/month/year) 19/04/1999	Priority date (day/month/year) 17/04/1998
International Patent Classification (IPC) or national classification and IPC B64G1/00		
Applicant TURBOSAT TECHNOLOGY, INC. et al.		

1. This international preliminary examination report has been prepared by this International Preliminary Examining Authority and is transmitted to the applicant according to Article 36.



2. This REPORT consists of a total of 5 sheets, including this cover sheet.

- ☒ This report is also accompanied by ANNEXES, i.e. sheets of the description, claims and/or drawings which have been amended and are the basis for this report and/or sheets containing rectifications made before this Authority (see Rule 70.16 and Section 607 of the Administrative Instructions under the PCT).

These annexes consist of a total of 84 sheets.

3. This report contains indications relating to the following items:

- I ☒ Basis of the report
- II ☐ Priority
- III ☐ Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
- IV ☐ Lack of unity of invention
- V ☒ Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement
- VI ☒ Certain documents cited
- VII ☐ Certain defects in the international application
- VIII ☐ Certain observations on the international application

Date of submission of the demand 15/11/1999	Date of completion of this report 27.09.2000
Name and mailing address of the international preliminary examining authority:  European Patent Office D-80298 Munich Tel. +49 89 2399 - 0 Tx: 523656 epmu d Fax: +49 89 2399 - 4465	Authorized officer Dorpema, H Telephone No. +49 89 2399 2885 

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

International application No. PCT/US99/08572

I. Basis of the report

1. This report has been drawn on the basis of (*substitute sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are not annexed to the report since they do not contain amendments.*):

Description, pages:

1, 2, 13, 17, 18,
21, 33, 34, 50,
51 as originally filed

3/1, 7, 14, 15, 16/1, as received on 28/02/2000 with letter of 24/02/2000
19, 22, 24/1, 25/1,
27-30, 38, 39, 41,
42, 44, 45/1, 48,
49, 53, 54-56

3/0/3, 6/1, 8/2/1, as received on 09/06/2000 with letter of 30/05/2000
16, 20, 26, 32,
35, 37, 40, 43,
45/0/1, 46, 46/0/1,
46/1, 47/3, 52

3, 3/0/0/1, 3/0/1, as received on 11/09/2000 with letter of 08/09/2000
3/0/2, 4, 4/1, 4/2,
5, 6, 8, 8/2, 9,
11, 12, 23, 24,
24/0/1, 25, 31,
31/1, 36, 45, 47,
47/2, 53/1

Claims, No.:

1-33 as received on 11/09/2000 with letter of 08/09/2000

Drawings, sheets:

1/19, 2/19, 5/19-7/19, as originally filed
11/19-19/19

3/19, 4/19, as received on 09/06/2000 with letter of 30/05/2000
8/19-10/19

**INTERNATIONAL PRELIMINARY
EXAMINATION REPORT**

International application No. PCT/US99/08572

2. The amendments have resulted in the cancellation of:

- ☒ the description, pages: 10
☐ the claims, Nos.:
☐ the drawings, sheets:

3. ☐ This report has been established as if (some of) the amendments had not been made, since they have been considered to go beyond the disclosure as filed (Rule 70.2(c)):

4. Additional observations, if necessary:

V. Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Statement

Novelty (N)	Yes:	Claims	1-33
	No:	Claims	
Inventive step (IS)	Yes:	Claims	1-33
	No:	Claims	
Industrial applicability (IA)	Yes:	Claims	1-33
	No:	Claims	

2. Citations and explanations

see separate sheet

VI. Certain documents cited

1. Certain published documents (Rule 70.10)

and / or

2. Non-written disclosures (Rule 70.9)

see separate sheet

V. Reasoned opinion under Article 35(2) with regard to novelty, inventive step and industrial applicability; citations and explanations supporting such statement

2. CITATIONS AND EXPLANATIONS

Claim 1

Closest prior art, see amended description page 3/0/1, is EP-A-0 447 049 (GEC-Marconi Ltd.) describing solar panels which are offset from their axes of rotation at the centre of radiator surfaces so that the panels obscure part of the radiator surfaces from the sun's rays, thereby lowering the solar irradiation on the radiator surfaces and increasing efficiency of the radiators. Disadvantageous are: the offset in mechanical terms, as well as the heat radiated by the solar panels themselves towards the radiator surface.

The subject-matter of amended claim 1 optimises the effective radiation view factor from the radiator surfaces to deep space by means including thermal insulation between a sun-facing surface of a blanking panel and an anti-sun-facing surface thereof, thereby inhibiting heat transfer through the blanking panel and thus decreasing heat radiating from the blanking plate to the radiator surface.

There is no lead in the available prior art to this expedient. Although EP-A-0 271 370 (CNES, see description page 3/0/1) does disclose a sun screen with thermal insulation, this appears to be more by way of a reflective coating on the sun-facing surface of the screen; in addition, the geometry of the screen (closely surrounding the radiator surface) does not give rise to the assumption that a general optimisation of the effective radiation view factor from the radiator surface to deep space is aimed at - rather, the solution disclosed mitigates only one aspect of disturbances to this effective view factor. The requirements of Articles 33(2) and (3) PCT are thus fulfilled; likewise, the requirements of Article 33(4) PCT is fulfilled.

Claims 2-33 depend on claim 1 and likewise fulfill the requirements of Article 33(2)-(4) PCT.

VI. Certain documents cited

1. Certain published documents (Rule 70.10)

**INTERNATIONAL PRELIMINARY
EXAMINATION REPORT - SEPARATE SHEET**

International application No. PCT/US99/08572

Document D4 has been published between the priority date of the present application and the filing date of the present application. The priority document corresponding to the present application was not available at the time this opinion was established, hence no check could be made as to the validity of the priority claimed.

PATENT COOPERATION TREATY

PCT

NOTIFICATION OF ELECTION

(PCT Rule 61.2)

From the INTERNATIONAL BUREAU

To:

Assistant Commissioner for Patents
United States Patent and Trademark
Office
Box PCT
Washington, D.C.20231
ÉTATS-UNIS D'AMÉRIQUE

in its capacity as elected Office

Date of mailing (day/month/year)

09 March 2000 (09.03.00)

International application No.

PCT/US99/08572

Applicant's or agent's file reference

P23293

International filing date (day/month/year)

19 April 1999 (19.04.99)

Priority date (day/month/year)

17 April 1998 (17.04.98)

Applicant

KASKIEWICZ, Paul et al

1. The designated Office is hereby notified of its election made:



in the demand filed with the International Preliminary Examining Authority on:

15 November 1999 (15.11.99)



in a notice effecting later election filed with the International Bureau on:

2. The election ☒ was

was not

made before the expiration of 19 months from the priority date or, where Rule 32 applies, within the time limit under Rule 32.2(b).

The International Bureau of WIPO
34, chemin des Colombettes
1211 Geneva 20, Switzerland

Facsimile No.: (41-22) 740.14.35

Authorized officer

Antonia Muller

Telephone No.: (41-22) 338.83.38

PATENT COOPERATION TREATY

PCT

From the INTERNATIONAL BUREAU

NOTIFICATION CONCERNING
SUBMISSION OR TRANSMITTAL
OF PRIORITY DOCUMENT

(PCT Administrative Instructions, Section 411)

To:

KASKIEWICZ, Paul, F.
P.O. Box 822
Princeton Junction, NJ 08550
ETATS-UNIS D'AMERIQUE

Date of mailing (day/month/year) 31 May 2000 (31.05.00)	IMPORTANT NOTIFICATION
Applicant's or agent's file reference P23293	
International application No. PCT/US99/08572	International filing date (day/month/year) 19 April 1999 (19.04.99)
International publication date (day/month/year) 03 February 2000 (03.02.00)	Priority date (day/month/year) 17 April 1998 (17.04.98)
Applicant TURBOSAT TECHNOLOGY, INC. et al	

1. The applicant is hereby notified of the date of receipt (except where the letters "NR" appear in the right-hand column) by the International Bureau of the priority document(s) relating to the earlier application(s) indicated below. Unless otherwise indicated by an asterisk appearing next to a date of receipt, or by the letters "NR", in the right-hand column, the priority document concerned was submitted or transmitted to the International Bureau in compliance with Rule 17.1(a) or (b).
2. This updates and replaces any previously issued notification concerning submission or transmittal of priority documents.
3. An asterisk(*) appearing next to a date of receipt, in the right-hand column, denotes a priority document submitted or transmitted to the International Bureau but not in compliance with Rule 17.1(a) or (b). In such a case, **the attention of the applicant is directed** to Rule 17.1(c) which provides that no designated Office may disregard the priority claim concerned before giving the applicant an opportunity, upon entry into the national phase, to furnish the priority document within a time limit which is reasonable under the circumstances.
4. The letters "NR" appearing in the right-hand column denote a priority document which was not received by the International Bureau or which the applicant did not request the receiving Office to prepare and transmit to the International Bureau, as provided by Rule 17.1(a) or (b), respectively. In such a case, **the attention of the applicant is directed** to Rule 17.1(c) which provides that no designated Office may disregard the priority claim concerned before giving the applicant an opportunity, upon entry into the national phase, to furnish the priority document within a time limit which is reasonable under the circumstances.

<u>Priority date</u>	<u>Priority application No.</u>	<u>Country or regional Office or PCT receiving Office</u>	<u>Date of receipt of priority document</u>
17 April 1998 (17.04.98)	09/062,594	US	03 May 2000 (03.05.00)

The International Bureau of WIPO 34, chemin des Colombettes 1211 Geneva 20, Switzerland Facsimile No. (41-22) 740.14.35	Authorized officer H. Zhou Telephone No. (41-22) 338.83.38
--------------------------------------------------------------------------------------------------------------------------------------	--------------------------------------------------------------------------

PATENT COOPERATION TREATY

PCT

COMMUNICATION IN CASES FOR WHICH
NO OTHER FORM IS APPLICABLE

From the INTERNATIONAL BUREAU

To:

KASKIEWICZ, Paul, F.
P.O.Box 822
Princeton Junction, NJ 08550
ÉTATS-UNIS D'AMÉRIQUE

Date of mailing (<i>day/month/year</i>) 21 December 1999 (21.12.1999)	
Applicant's or agent's file reference P23293	REPLY DUE see paragraph 1 below
International application No. PCT/US99/08572	International filing date (<i>day/month/year</i>) 19 April 1999 (19.04.1999)
Applicant TURBOSAT TECHNOLOGY, INC.	

1. ☐ REPLY DUE within _____ months/days from the above date of mailing

☐ NO REPLY DUE, however, see below

☒ IMPORTANT COMMUNICATION

☐ INFORMATION ONLY

2. COMMUNICATION:

The International Bureau regrets to inform the applicant that, due to late receipt of the record copy, the above identified international application has not been published promptly after the expiration of 18 months from the priority date, as provided in PCT Article 21(2)(a).

International publication will now take place on 03 February 2000 (03.02.2000).

Meanwhile, the International Bureau will communicate a copy of the international application to each designated Office, in accordance with PCT Article 20.

A copy of this notification has been sent to the receiving Office (RO/US); and the designated Office(s).

The International Bureau of WIPO 34, chemin des Colombettes 1211 Geneva 20, Switzerland	Authorized officer H. Zhou
Facsimile No. (41-22) 740.14.35	Telephone No. (41-22) 338.83.38

PATENT COOPERATION TREATY

PCT

COMMUNICATION OF
INTERNATIONAL APPLICATIONS

(PCT Article 20)

From the INTERNATIONAL BUREAU

To:

Assistant Commissioner for Patents
United States Patent and Trademark
Office
Box PCT
Washington, D.C.20231
ÉTATS-UNIS D'AMÉRIQUE

in its capacity as designated Office

Date of mailing:

21 December 1999 (21.12.99)

The International Bureau transmits herewith copies of the international applications having the following international application numbers and international publication numbers:

International application no.:

PCT/US99/08572

International publication no.:The International Bureau of WIPO
34, chemin des Colombettes
1211 Geneva 20, Switzerland

Facsimile No.: (41-22) 740.14.35

Authorized officer:

J. Zahra
Telephone No.: (41-22) 338.83.38

From the
INTERNATIONAL PRELIMINARY EXAMINING AUTHORITY

To:

KASKIEWICZ, Paul
P.O.Box 822
Princeton Junction, N.J.08550
ETATS-UNIS D'AMERIQUE

PCT

NOTIFICATION OF TRANSMITTAL OF
THE INTERNATIONAL PRELIMINARY
EXAMINATION REPORT

(PCT Rule 71.1)

Date of mailing
(day/month/year) 27.09.2000

Applicant's or agent's file reference
./.

IMPORTANT NOTIFICATION

International application No.
PCT/US99/08572

International filing date (day/month/year)
19/04/1999

Priority date (day/month/year)
17/04/1998

Applicant
TURBOSAT TECHNOLOGY, INC. et al.

1. The applicant is hereby notified that this International Preliminary Examining Authority transmits herewith the international preliminary examination report and its annexes, if any, established on the international application.
2. A copy of the report and its annexes, if any, is being transmitted to the International Bureau for communication to all the elected Offices.
3. Where required by any of the elected Offices, the International Bureau will prepare an English translation of the report (but not of any annexes) and will transmit such translation to those Offices.

4. REMINDER

The applicant must enter the national phase before each elected Office by performing certain acts (filing translations and paying national fees) within 30 months from the priority date (or later in some Offices) (Article 39(1)) (see also the reminder sent by the International Bureau with Form PCT/IB/301).

Where a translation of the international application must be furnished to an elected Office, that translation must contain a translation of any annexes to the international preliminary examination report. It is the applicant's responsibility to prepare and furnish such translation directly to each elected Office concerned.

For further details on the applicable time limits and requirements of the elected Offices, see Volume II of the PCT Applicant's Guide.

Name and mailing address of the IPEA/



European Patent Office
D-80298 Munich
Tel. +49 89 2399 - 0 Tx: 523656 epmu d
Fax: +49 89 2399 - 4465

Authorized officer

Murphy-Minehane, B

Tel +49 89 2399-2753



RECORD COPY

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REQUEST

The undersigned requests that the present international application be processed according to the Patent Cooperation Treaty.

For receiving Office use only	
International Application No.	PCT/US 99 / 085 7 2
International Filing Date	(19.04.99) 19 APR 1999
PCT INTERNATIONAL APPLICATION RO/US	
Name of receiving Office and "PCT International Application"	
Applicant's or agent's file reference (if desired) (12 characters maximum)	P23293

Box No. I	TITLE OF INVENTION SPACECRAFT	
Box No. II	APPLICANT	
Name and address: (Family name followed by given name; for a legal entity, full official designation. The address must include postal code and name of country. The country of the address indicated in this Box is the applicant's State (that is, country) of residence if no State of residence is indicated below.) TURBOSAT TECHNOLOGY, INC. P.O. Box 822 Princeton Junction New Jersey 08550 United States of America		<input type="checkbox"/> This person is also inventor. Telephone No. -- Facsimile No. Teleprinter No.
State (that is, country) of nationality: United States of America		State (that is, country) of residence: United States of America
This person is applicant for the purposes of: <input type="checkbox"/> all designated States <input checked="" type="checkbox"/> all designated States except the United States of America <input type="checkbox"/> the United States of America only <input type="checkbox"/> the States indicated in the Supplemental Box		
Box No. III	FURTHER APPLICANT(S) AND/OR (FURTHER) INVENTOR(S)	
Name and address: (Family name followed by given name; for a legal entity, full official designation. The address must include postal code and name of country. The country of the address indicated in this Box is the applicant's State (that is, country) of residence if no State of residence is indicated below.) KASKIEWICZ, Paul 216 East Street Philadelphia Pennsylvania 19128 United States of America		This person is: <input type="checkbox"/> applicant only <input checked="" type="checkbox"/> applicant and inventor <input type="checkbox"/> inventor only (If this check-box is marked, do not fill in below.)
State (that is, country) of nationality: United States of America		State (that is, country) of residence: United States of America
This person is applicant for the purposes of: <input checked="" type="checkbox"/> all designated States <input type="checkbox"/> all designated States except the United States of America <input type="checkbox"/> the United States of America only <input type="checkbox"/> the States indicated in the Supplemental Box		
<input checked="" type="checkbox"/> Further applicants and/or (further) inventors are indicated on a continuation sheet.		
Box No. IV	AGENT OR COMMON REPRESENTATIVE; OR ADDRESS FOR CORRESPONDENCE	
The person identified below is hereby/has been appointed to act on behalf of the applicant(s) before the competent International Authorities as: * <input checked="" type="checkbox"/> agent <input checked="" type="checkbox"/> common representative		
Name and address: (Family name followed by given name; for a legal entity, full official designation. The address must include postal code and name of country.) GALLOWAY, Peter D. Ladas & Parry 26 West 61st Street New York, New York 10023 United States of America		Telephone No. 212-708-1905 Facsimile No. 212-2468959 Teleprinter No.
<input type="checkbox"/> Address for correspondence: Mark this check-box where no agent or common representative is/has been appointed and the space above is used instead to indicate a special address to which correspondence should be sent.		

EE784103876US

* See #4

Continuation of Box No. III FURTHER APPLICANT(S) AND/OR (FURTHER) INVENTOR(S)

If none of the following sub-boxes is used, this sheet should not be included in the request.

Name and address: (Family name followed by given name; for a legal entity, full official designation. The address must include postal code and name of country. The country of the address indicated in this Box is the applicant's State (that is, country) of residence if no State of residence is indicated below.)

LIU, Linchih Oliver
12 Indian Run Road
Princeton, New Jersey 08550
United States of America

This person is:

- ☐ applicant only
☒ applicant and inventor
☐ inventor only (If this check-box is marked, do not fill in below.)

State (that is, country) of nationality:
United States of America

State (that is, country) of residence:
United States of America

This person is applicant for the purposes of:

☐ all designated States

☐ all designated States except the United States of America

☒ the United States of America only

☐ the States indicated in the Supplemental Box

Name and address: (Family name followed by given name; for a legal entity, full official designation. The address must include postal code and name of country. The country of the address indicated in this Box is the applicant's State (that is, country) of residence if no State of residence is indicated below.)

WU, Albert T.
167 West Mudland Avenue
Paramus, New Jersey 07652
United States of America

This person is:

- ☐ applicant only --
☒ applicant and inventor
☐ inventor only (If this check-box is marked, do not fill in below.)

State (that is, country) of nationality:
United States of America

State (that is, country) of residence:
United States of America

This person is applicant for the purposes of:

☐ all designated States

☐ all designated States except the United States of America

☒ the United States of America only

☐ the States indicated in the Supplemental Box

Name and address: (Family name followed by given name; for a legal entity, full official designation. The address must include postal code and name of country. The country of the address indicated in this Box is the applicant's State (that is, country) of residence if no State of residence is indicated below.)

This person is:

- ☐ applicant only
☐ applicant and inventor
☐ inventor only (If this check-box is marked, do not fill in below.)

State (that is, country) of nationality:

State (that is, country) of residence:

This person is applicant for the purposes of:

☐ all designated States

☐ all designated States except the United States of America

☐ the United States of America only

☐ the States indicated in the Supplemental Box

Name and address: (Family name followed by given name; for a legal entity, full official designation. The address must include postal code and name of country. The country of the address indicated in this Box is the applicant's State (that is, country) of residence if no State of residence is indicated below.)

This person is:

- ☐ applicant only
☐ applicant and inventor
☐ inventor only (If this check-box is marked, do not fill in below.)

State (that is, country) of nationality:

State (that is, country) of residence:

This person is applicant for the purposes of:

☐ all designated States

☐ all designated States except the United States of America

☐ the United States of America only

☐ the States indicated in the Supplemental Box

☐ Further applicants and/or (further) inventors are indicated on another continuation sheet.

Box No.V DESIGNATION OF STATES

The following designations are hereby made under Rule 4.9(a) (mark the applicable check-boxes; at least one must be marked):

Regional Patent

- ☐ **AP** ARIPO Patent: GH Ghana, GM Gambia, KE Kenya, LS Lesotho, MW Malawi, SD Sudan, SZ Swaziland, UG Uganda, ZW Zimbabwe, and any other State which is a Contracting State of the Harare Protocol and of the PCT
- ☐ **EA** Eurasian Patent: AM Armenia, AZ Azerbaijan, BY Belarus, KG Kyrgyzstan, KZ Kazakhstan, MD Republic of Moldova, RU Russian Federation, TJ Tajikistan, TM Turkmenistan, and any other State which is a Contracting State of the Eurasian Patent Convention and of the PCT
- ☒ **EP** European Patent: AT Austria, BE Belgium, CH and LI Switzerland and Liechtenstein, CY Cyprus, DE Germany, DK Denmark, ES Spain, FI Finland, FR France, GB United Kingdom, GR Greece, IE Ireland, IT Italy, LU Luxembourg, MC Monaco, NL Netherlands, PT Portugal, SE Sweden, and any other State which is a Contracting State of the European Patent Convention and of the PCT
- ☐ **OA** OAPI Patent: BF Burkina Faso, BJ Benin, CF Central African Republic, CG Congo, CI Côte d'Ivoire, CM Cameroon, GA Gabon, GN Guinea, GW Guinea-Bissau, ML Mali, MR Mauritania, NE Niger, SN Senegal, TD Chad, TG Togo, and any other State which is a member State of OAPI and a Contracting State of the PCT (if other kind of protection or treatment desired, specify on dotted line)

National Patent (if other kind of protection or treatment desired, specify on dotted line):

- | | |
|--------------------------------------------------------------------------------|------------------------------------------------------------------------------------|
| <input type="checkbox"/> AL Albania | <input type="checkbox"/> LS Lesotho |
| <input type="checkbox"/> AM Armenia | <input type="checkbox"/> LT Lithuania |
| <input type="checkbox"/> AT Austria | <input type="checkbox"/> LU Luxembourg |
| <input checked="" type="checkbox"/> AU Australia | <input type="checkbox"/> LV Latvia |
| <input type="checkbox"/> AZ Azerbaijan | <input type="checkbox"/> MD Republic of Moldova |
| <input type="checkbox"/> BA Bosnia and Herzegovina | <input type="checkbox"/> MG Madagascar |
| <input type="checkbox"/> BB Barbados | <input type="checkbox"/> MK The former Yugoslav Republic of Macedonia |
| <input type="checkbox"/> BG Bulgaria | <input type="checkbox"/> MN Mongolia |
| <input type="checkbox"/> BR Brazil | <input type="checkbox"/> MW Malawi |
| <input type="checkbox"/> BY Belarus | <input type="checkbox"/> MX Mexico |
| <input checked="" type="checkbox"/> CA Canada | <input type="checkbox"/> NO Norway |
| <input type="checkbox"/> CH and LI Switzerland and Liechtenstein | <input type="checkbox"/> NZ New Zealand |
| <input checked="" type="checkbox"/> CN China | <input type="checkbox"/> PL Poland |
| <input type="checkbox"/> CU Cuba | <input type="checkbox"/> PT Portugal |
| <input type="checkbox"/> CZ Czech Republic | <input type="checkbox"/> RO Romania |
| <input type="checkbox"/> DE Germany | <input checked="" type="checkbox"/> RU Russian Federation |
| <input type="checkbox"/> DK Denmark | <input type="checkbox"/> SD Sudan |
| <input type="checkbox"/> EE Estonia | <input type="checkbox"/> SE Sweden |
| <input type="checkbox"/> ES Spain | <input type="checkbox"/> SG Singapore |
| <input type="checkbox"/> FI Finland | <input type="checkbox"/> SI Slovenia |
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| <input type="checkbox"/> GE Georgia | <input type="checkbox"/> TJ Tajikistan |
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| <input type="checkbox"/> HR Croatia | <input type="checkbox"/> TT Trinidad and Tobago |
| <input type="checkbox"/> HU Hungary | <input type="checkbox"/> UA Ukraine |
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| <input type="checkbox"/> IL Israel | <input checked="" type="checkbox"/> US United States of America |
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| <input type="checkbox"/> KG Kyrgyzstan | <input type="checkbox"/> ZW Zimbabwe |
| <input type="checkbox"/> KP Democratic People's Republic of Korea | |
| <input checked="" type="checkbox"/> KR Republic of Korea | |
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Check-boxes reserved for designating States (for the purposes of a national patent) which have become party to the PCT after issuance of this sheet:

- ☐
- ☐
- ☐

Precautionary Designation Statement: In addition to the designations made above, the applicant also makes under Rule 4.9(b) all other designations which would be permitted under the PCT except any designation(s) indicated in the Supplemental Box as being excluded from the scope of this statement. The applicant declares that those additional designations are subject to confirmation and that any designation which is not confirmed before the expiration of 15 months from the priority date is to be regarded as withdrawn by the applicant at the expiration of that time limit. (Confirmation of a designation consists of the filing of a notice specifying that designation and the payment of the designation and confirmation fees. Confirmation must reach the receiving Office within the 15-month time limit.)

Supplemental Box

If the Supplemental Box is not used, this sheet should not be included in the request.

1. If, in any of the Boxes, the space is insufficient to furnish all the information: in such case, write "Continuation of Box No. ..." [Indicate the number of the Box] and furnish the information in the same manner as required according to the captions of the Box in which the space was insufficient, in particular:

- (i) if more than two persons are involved as applicants and/or inventors and no "continuation sheet" is available: in such case, write "Continuation of Box No. III" and indicate for each additional person the same type of information as required in Box No. III. The country of the address indicated in this Box is the applicant's State (that is, country) of residence if no State of residence is indicated below;
- (ii) if, in Box No. II or in any of the sub-boxes of Box No. III, the indication "the States Indicated in the Supplemental Box" is checked: in such case, write "Continuation of Box No. II" or "Continuation of Box No. III" or "Continuation of Boxes No. II and No. III" (as the case may be), indicate the name of the applicant(s) involved and, next to (each) such name, the State(s) (and/or, where applicable, ARIPO, Eurasian, European or OAPI patent) for the purposes of which the named person is applicant;
- (iii) if, in Box No. II or in any of the sub-boxes of Box No. III, the inventor or the inventor/applicant is not inventor for the purposes of all designated States or for the purposes of the United States of America: in such case, write "Continuation of Box No. II" or "Continuation of Box No. III" or "Continuation of Boxes No. II and No. III" (as the case may be), indicate the name of the inventor(s) and, next to (each) such name, the State(s) (and/or, where applicable, ARIPO, Eurasian, European or OAPI patent) for the purposes of which the named person is inventor;
- (iv) if, in addition to the agent(s) indicated in Box No. IV, there are further agents: in such case, write "Continuation of Box No. IV" and indicate for each further agent the same type of information as required in Box No. IV;
- (v) if, in Box No. V, the name of any State (or OAPI) is accompanied by the indication "patent of addition," or "certificate of addition," or if, in Box No. V, the name of the United States of America is accompanied by an indication "continuation" or "continuation-in-part": in such case, write "Continuation of Box No. V" and the name of each State involved (or OAPI), and after the name of each such State (or OAPI), the number of the parent title or parent application and the date of grant of the parent title or filing of the parent application;
- (vi) if, in Box No. VI, there are more than three earlier applications whose priority is claimed: in such case, write "Continuation of Box No. VI" and indicate for each additional earlier application the same type of information as required in Box No. VI;
- (vii) if, in Box No. VI, the earlier application is an ARIPO application: in such case, write "Continuation of Box No. VI", specify the number of the item corresponding to that earlier application and indicate at least one country party to the Paris Convention for the Protection of Industrial Property for which that earlier application was filed.

2. If, with regard to the precautionary designation statement contained in Box No. V, the applicant wishes to exclude any State(s) from the scope of that statement: in such case, write "Designation(s) excluded from precautionary designation statement" and indicate the name or two-letter code of each State so excluded.

3. If the applicant claims, in respect of any designated Office, the benefits of provisions of the national law concerning non-prejudicial disclosures or exceptions to lack of novelty: in such case, write "Statement concerning non-prejudicial disclosures or exceptions to lack of novelty" and furnish that statement below.

CONTINUATION OF BOX NO. IV.

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CONTINUATION OF BOX NO. V.

United States of America Application No. 09/062,594
Filed 17 April 1998 (17.04.98)

Box No. VI PRIORITY CLAIM		<input type="checkbox"/> Further priority claims are indicated in the Supplemental Box.		
Filing date of earlier application (day/month/year)	Number of earlier application	Where earlier application is:		
		national application: country	regional application: regional Office	international application: receiving Office
item (1) 17 April 1998 (17.04.98)	09/062,594	US		
item (2)				
item (3)				

☒ The receiving Office is requested to prepare and transmit to the International Bureau a certified copy of the earlier application(s) (only if the earlier application was filed with the Office which for the purposes of the present international application is the receiving Office) identified above as item(s): (1)

* Where the earlier application is an ARIPO application, it is mandatory to indicate in the Supplemental Box at least one country party to the Paris Convention for the Protection of Industrial Property for which that earlier application was filed (Rule 4.10(b)(ii)). See Supplemental Box.

Box No. VII INTERNATIONAL SEARCHING AUTHORITY

Choice of International Searching Authority (ISA)
(if two or more International Searching Authorities are competent to carry out the international search, indicate the Authority chosen; the two-letter code may be used):

ISA / EP

Request to use results of earlier search; reference to that search (if an earlier search has been carried out by or requested from the International Searching Authority):

Date (day/month/year)

Number

Country (or regional Office)

Box No. VIII CHECK LIST; LANGUAGE OF FILING

This international application contains the following number of sheets:

request : 5
description (excluding sequence listing part) : 56
claims : 8
abstract : 1
drawings : 19
sequence listing part of description :
Total number of sheets : 89

This international application is accompanied by the item(s) marked below:

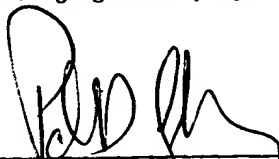
- ☒ fee calculation sheet
- ☐ separate signed power of attorney
- ☐ copy of general power of attorney; reference number, if any:
- ☐ statement explaining lack of signature
- ☐ priority document(s) identified in Box No. VI as item(s):
- ☐ translation of international application into (language):
- ☐ separate indications concerning deposited microorganism or other biological material
- ☐ nucleotide and/or amino acid sequence listing in computer readable form
- ☒ other (specify): Transmittal Letter

Figure of the drawings which should accompany the abstract: 5

Language of filing of the international application: English

Box No. IX SIGNATURE OF APPLICANT OR AGENT

Next to each signature, indicate the name of the person signing and the capacity in which the person signs (if such capacity is not obvious from reading the request).


PETER D. GALLOWAY
ATTORNEY FOR APPLICANTS

(19.04.99)

For receiving Office use only		2. Drawings: <input type="checkbox"/> received: <input type="checkbox"/> not received:
1. Date of actual receipt of the purported international application:	430 Rec'd PCT/PTO - 19 APR 1999	
3. Corrected date of actual receipt due to later but timely received papers or drawings completing the purported international application:		
4. Date of timely receipt of the required corrections under PCT Article 11(2):		
5. International Searching Authority (if two or more are competent): ISA / EP	6. <input type="checkbox"/> Transmittal of search copy delayed until search fee is paid.	

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Date of receipt of the record copy by the International Bureau:	17 DECEMBER 1999 (17.12.99)

and rotatable therewith. Thereby, the shading device will always be disposed between the Sun and the de-spun platform. However, the shading device also blocks thermal radiation from the platform and also itself heats
5 up in sunlight and radiates heat towards the platform, decreasing the efficiencies of heat transfer from the spacecraft to space.

Notwithstanding the prior art, the present invention
10 is neither taught nor rendered obvious thereby.

It is an object of this invention substantially to reduce or eliminate the direct and indirect solar heating of certain spacecraft radiator-panels, and to also
15 minimize the magnitude of any reduction in the radiative-view-factor of the (shielded) radiator panel. In order to achieve that objective, the materials and design selected for the sun ray blocker device, which will be discussed below, should ideally provide all of the
20 following: minimum blockage of the field-of-view to deep space of its associated radiator surface(s), low absorption of the solar energy incident on its front (sunward) surface, high radiation of absorbed thermal energy back to space, and high insulation of heat between
25 the front (sunward) and back (anti-sunward) sides of the sun ray blocker device.

It is also desirable to provide a sun ray blocker device that is capable of greatly reducing or eliminating
30 solar energy incident on those sides of certain spacecraft relative to which the Sun direction makes a low angle. The types of spacecraft to which the present

invention applies include some spacecraft for operation in equatorial or low inclination orbits, and in sun synchronous orbits with low orbit-sun angles. In the case of three-axis stabilized, Earth-pointing, 5 geostationary spacecraft for example, these shaded sides are either or both of the north and south main-body panels. In the case of the sun synchronous spacecraft for example, the shaded sides are either or both of the sides or main-body panels that face out along the pitch 10 axis (i.e. that face parallel to the orbit normal and anti-normal). The present invention can also be applied to types of spacecraft, other than geostationary and sun synchronous types, upon which the solar illumination is incident at low angles relative to thermal radiator 15 surface. In those spacecraft it is those main thermal radiator surface that can be shaded by the present invention device.

According to a first embodiment of the invention 20 there is provided a spacecraft for orbiting a sunlit celestial body, the spacecraft including a thermal radiator surface for radiating heat from the spacecraft into space, and a sun-ray blocker device mounted on said spacecraft for shielding said thermal radiator surface 25 from rays of sunlight, characterised in that said sun ray blocker device is locatable for placing in shadow substantially the whole of the thermal radiator surface from sunlight without substantially impeding thermal radiation from said thermal radiator surface into space.

30 Preferably an effective radiation view factor for thermal radiation from the thermal radiator surface

(11,12,1804, 2121,2721) to deep space is significantly greater than corresponding geometrical radiation view factor to deep space, and in particular, for a geostationary spacecraft where the geometrical radiation
5 view factor to deep space is 0.65, the effective radiation view factor to deep space is at least 0.87.

A preferred inventive feature will be seen to reside in the sun ray blocker device including at least one sun blocker panel having a sun-facing surface and an opposed
10 anti-sun-facing surface, wherein the sun-facing surface is thermally insulated from the opposed surface.

Conveniently the sun-facing surface is thermally insulated from the opposed surface by a multi-layer insulation blanket.

15 Advantageously the sun-facing surface has a low solar energy absorptivity of less than 0.5.

Advantageously the sun-facing surface includes a solar cell panel for supplying electrical power to the spacecraft.

20 Preferably the sun-facing surface has a high thermal emissivity of higher than 0.7.

A preferred inventive feature will be seen to reside in the sun ray blocker device being moveable between a stowed, non-operative position and a deployed operative
25 position.

Conveniently the sun ray blocker device includes an attachment arm for attaching the sun blocker panel to the spacecraft.

Advantageously the attachment arm is attached by a hinge means to the sun blocker panel and/or by a second hinge means to the spacecraft.

Advantageously the sun ray blocker device includes a
5 motor for moving the sun ray blocker device between the stowed position and the deployed position.

Preferably locating means are provided for locating the sun ray blocker device with respect to the thermal radiator surface which include adjustment means to
10 maintain the majority of the thermal radiator surface in shadow irrespective of changes in the attitude and/or orbit of the spacecraft.

Advantageously the adjustment means includes carriage means (1801, 1901, 2001) for carrying the sun
15 blocker panel (1800, 1900, 2000) and transport means (1802, 1808, 1903, 1904, 2003, 2006) for moving the carriage with respect to the spacecraft.

Conveniently the transport means includes rail means (1802) and the carriage means (1801) includes drive means
20 to drive the carriage along the rail means.

Preferably the transport means includes an annulus rotatable in circular path defined by bearing means, the annulus being driveable by drive means to move the carriage along the path defined by the bearing means.

25 Alternatively the transport means includes rail means (1902) and belt means (1903) connected to the carriage means (1901), the belt means being driven by

drive means (1904) to move the carriage means along the rail means (1902).

Conveniently the adjustment means includes a variable length attachment arm (2101, 2703) for attachment
5 of the sun blocker panel (2100, 2700) to a solar cell array assembly (2103, 2701) for rotation with the solar cell array assembly, such that the distance of the sun blocker panel from the solar cell array assembly may be varied during rotation.

10 Alternatively the spacecraft has a solar cell array adapted for tracking movements of the sun relative to the spacecraft, wherein the adjustment of the location of the sun ray blocker device in relation to the thermal radiator surface is synchronised with the tracking
15 movement of the solar cell array, when in normal operation.

Conveniently the sun ray blocker device is mounted on the solar cell array or on means carry said solar cell array.

20 Advantageously the solar cell array tracks the movement of the sun by rotation of the solar cell array about an axis of rotation of the solar cell array such that the sun blocker panel also rotates about said axis of rotation of the solar cell array.

25 Conveniently the thermal radiator surface is orthogonal to the axis of rotation of the solar cell array so that the sun blocker panel rotates about an axis normal to the thermal radiator surface.

Advantageously adjustment means includes a variable length attachment arm for attachment of the sun blocker panel to the spacecraft.

Advantageously the attachment arm is a scissor arm
5 (2703).

Alternatively the attachment arm (2101) is formed of articulated portions (2104, 2105, 2106) which may be mutually articulated during rotation to vary an effective length of the attachment arm.

10 Conveniently adjustment means for attachment of the sun blocker panel to a solar cell array assembly are such that a distance between the sun blocker panel and the solar cell array assembly may be varied during rotation of the sun blocker panel.

15 Conveniently means are provided for adjusting the size of the sun blocker panel.

Conveniently the spacecraft includes control means for controlling the spacecraft so as to maintain an angle between a sun line and the thermal radiator surface below
20 a predetermined angle by adjustment of the orbit and/or attitude of the spacecraft in use.

Preferably the predetermined angle is 60 degrees.

More preferably the predetermined angle is 45 degrees.

25 Most preferably the predetermined angle is 23.5 degrees.

Advantageously the control means is adapted to maintain the thermal radiator surface substantially parallel to a plane of an orbit of the spacecraft.

Alternatively the control means is adapted to
5 maintain the spacecraft in a sun synchronous orbit.

Alternatively, the control means is adapted to maintain the spacecraft in an equatorial or low-inclination orbit.

According to another embodiment of the invention
10 there is provided in a three axis stabilised spacecraft for orbiting about a planet and having at least one solar cell assembly having at least one solar cell panel, and being a north solar cell panel assembly or a south solar cell panel assembly, said at least one solar cell panel
15 assembly being mounted on an axle so as to be controllably rotated from said spacecraft about an axis of rotation so as to face the sun, said spacecraft having a nadir panel which is generally pointing to the centre of the planet, an opposite panel known as a zenith panel,
20 which faces away from the centre of the planet and sharing the same planar normal vector as said nadir panel, an east panel and a west panel, said east panel and said west panel having their planar normal vector laying on a orbital plane pointing to the velocity vector
25 of the spacecraft generally tangential to the direction of travel on the orbit, and a north panel and a south panel, said north panel and said south panel having their planar normal vector generally perpendicular to the orbit plane and parallel to the axis of rotation of the planet,

velocity vector of the spacecraft generally tangential to the direction of travel on the orbit, and a north panel and a south panel, said north panel and said south panel having their planar normal vector generally perpendicular
5 to the orbit plane and parallel to the axis of rotation of the earth, said solar cell panel extending outwardly from said spacecraft, the improvement which comprises:

attaching at least one sun ray blocker device to each of said north solar array and said south solar
10 array, one device being a north device and another device being a south device, each of said sun ray blocker devices being in the form of a panel and being positioned forwardly and offset relative to the solar cell surface of a solar ray and at a predetermined angle to said north
15 panel and said south panel, said north blocker device being positioned so as to cast a shadow on at least a majority of the exposed surface of said north panel during solar exposure thereto, and said south blocker device being positioned so as to cast a shadow on the
20 exposed surface of said south panel during solar exposure thereto.

The present invention preferably provides a sun-
25 synchronous sun ray blocker device (not to be confused with sun synchronous orbits referred to elsewhere herein) for use in a spacecraft designed to orbit around a planet with solar incidence at low angles to their thermal radiator surfaces, i.e. with sun directions close
30 to the planes of the individual radiator surfaces. Preferred embodiments of the present invention are spacecraft for operating in an orbit plane oriented at a

low angle (or within a range of low angles) to the sun direction, the said spacecraft having a thermal radiator surface that is oriented approximately parallel to the orbit plane and a solar array assembly that is rotated
5 about an axis approximately perpendicular to the orbit plane nominally at the orbital rate. Examples of appropriate orbits are: (a) low inclination orbits around the Earth (including nominally equatorial orbits), and
10 (b) sun synchronous orbits with low orbit-sun angles (which around Earth and Mars, for example, are nominally polar orbits). The term "spacecraft" as used herein includes satellites and other space bound vehicles.

Mounted on any spacecraft to which the present
15 invention is applied is at least one device for blocker sun rays and thereby preventing them from directly impinging on a radiator surfaces of the spacecraft.

In many embodiments of the present invention the
20 individual spacecraft will have at least one solar array assembly (comprised of solar cell panels and rotary axial booms) which may be used as mounting support for the sun ray blocker device(s), so that the combination assembly of solar array assembly and sun blocker device(s) is
25 operationally controllably rotated together as an integral unit to track the Sun throughout the orbital revolutions of the spacecraft, said solar array assembly being mounted on the spacecraft so that operationally in orbit it can be rotated about an axis that is maintained
30 oriented approximately perpendicular to the orbit plane in a manner such that the solar-cell side of the solar cell panels is maintained sun facing and substantially

of weather monitoring and remote sensing of the planet and its atmosphere. Some of the benefits of these sun synchronous orbits are: low spacecraft altitudes, frequent over-flight of the planet within close proximity
5 of virtually all latitudes and longitudes, and near constant angle of solar illumination on the day side of the orbit.

Means of adjusting the attitude and orbit of
10 spacecraft are well known, for example, are described in "Principals of Communication Satellites" by Gary D Gordan and Walter L Morgan published by John Wiley & Sons 1993, pages 12-14, 55-58 and in "Spacecraft Attitudes, Termination and Control" by James R Wertz published by
15 Kluwer Academic Publishers 1978. Attitude and orbit control may for example be provided by the use of thrusters and/or momentum or reaction wheels.

Typically, the attitude (i.e. the orientation) of
20 these types of satellite is controlled so that as the satellite orbits the planet part of its payload equipment steadily faces approximately toward the center of the planet, while the solar arrays are maintained sun pointing. The attitude (orientation) control systems of
25 such spacecraft belong to various classifications that are well known within the space industry. For example, two of the more currently prominent types of attitude control system are commonly referred to as "three-axis-stabilized" control systems and "spin stabilized" control
30 systems. The present invention device functions independently of the type of attitude control system, and independently of the orientation of spacecraft equipment

other than the orientation of the thermal radiator surfaces that the device shields from solar energy. In these types of spacecraft, the performance of the present invention device is generally better the closer the
5 shadowed thermal radiator surface is to being parallel to the orbit plane (which in these types of spacecraft is maintainable at a low angle to the sun line).

Hereinafter, the concept of a "model spacecraft" is defined and employed in order to avoid the distraction of
10 multiple lengthy descriptions of diverse spacecraft to which the present invention device may be applied. The model spacecraft is used herein, somewhat like a tailor's dummy, in order to facilitate the illustration and explanation of features, functions, and examples of
15 applications of the present invention device.

By definition the model spacecraft has a basic, deployed (i.e. unfolded), structural configuration that is typical of many current three axis stabilized
20 satellites, and a corresponding operational mode that is typical of a geostationary Earthpointing spacecraft. Note that this definition was selected on the basis of current estimates of the most frequent future application of the present invention device. The definition of the
25 model spacecraft could equally well have been based on typical characteristics of another relevant type of spacecraft, for example an Earth-pointing spacecraft in a sun synchronous orbit with a low orbit-Sun angle.

30 Referring to FIGURES 1 and 5, the basic structural configuration of the model spacecraft is based on a main body in the form of a hollow, right parallelepiped. For

the stated purposes of using the concept of the "model spacecraft" herein, it is useful to consider the main body as being comprised of six principal, planar, structural panels. The external surfaces of one opposing pair of the six panels that form the main body of the model spacecraft constitute the mounting sites for the thermal radiator surfaces that are shielded from direct solar heating by means of the present invention device. Mounted on one or each of these two radiator-bearing panels, and extending perpendicularly outwards therefrom, is a solar array assembly, comprised of a rotary solar array boom to which are attached solar cell panels.

That is not to say that application of the present invention device is limited to spacecraft resembling the structural configuration and operational mode of the model spacecraft. For example, the present invention device is also applicable to: sun synchronous spacecraft in orbits with low orbit-Sun angles; spin stabilized spacecraft; spacecraft with polyhedral and/or irregular structures; spacecraft that are not nadir pointing; spacecraft with solar arrays that deploy and subsequently lie along axes that are not perpendicular to the radiator-bearing panels; etc.

25

Much of the text herein that supports the accompanying claims is written with reference to the model spacecraft. Regardless, the supporting text also applies to applications of the present invention device to other suitable types of spacecraft. For example, the principal relevant difference between many suitable sun synchronous spacecraft (for polar orbits at Earth and

30

like the model spacecraft are referred to as the north and south panels.

To avoid unnecessary further repetition, to
5 illustrate and explain the features and functions of the
present invention device, reference shall be made to
application to the (previously defined) model satellite,
which is operated in a three-axis-stabilized, Earth-
pointing, geosynchronous mode. (That is not to say that
10 application of the present invention device is limited to
spacecraft that resemble the previously described model
spacecraft and/or are operated in the corresponding mode.
For example, the present invention device is also
applicable to spin stabilized spacecraft with irregularly
15 shaped structures that are neither nadir pointed nor
geosynchronous.)

Through each orbital revolution of a spacecraft like
the model spacecraft, which in a preferred embodiment is
20 around the Earth, the Sun sequentially directly
illuminates the east, zenith, west, and nadir main-body
panels. While illuminated (or insolated) thus these main-
body panels absorb incident solar energy and their
temperatures increase, which significantly reduces their
25 net radiative cooling capability. If not countered by
some means this can significantly limit the quantity of
equipment (which dissipate heat into the spacecraft) that
can be carried on board, and/or can result in undesirably
elevated temperatures of associated spacecraft equipment.
30 The north and south panels, however, generally face deep
space during the entire orbit and only directly receive
solar illumination and solar energy at relatively low

incidence angles on a seasonal basis. Because the direct input of solar energy into the north and south panels is relatively low to zero, these panels are the principal sites on spacecraft like the model spacecraft for the
5 locations of thermal-energy radiator surfaces. The north panel is directly heated by the Sun for a duration of about 6 months (from about March 21st to about October 21st) at an incidence angle, defined as the angle between the panel plane and the sun vector, which seasonally
10 increases from 0 degrees (when the sun vector is edge-on to the panel) to about 23.5 degrees followed by a decrease to 0 degrees again while the Sun is on the north side of the earth equator, i.e. during the northern spring and summer. The south panel is directly heated by
15 the Sun for the remainder of the year, i.e. during the southern spring and summer, in a similar fashion and concomitantly with the north panel. These relatively low solar incidence angles favor use of the north and south panels for locating the principal thermal radiator
20 surfaces of the spacecraft. At a maximum incidence angle of 23.5 degrees for the solar vector relative to the north and south panels the incident solar energy is approximately 40% of that for normal (perpendicular) incidence.

25

In the prior art numerous design practices have been employed to the surface treatment of the north and south panels in an effort to reduce the absorbed solar energy, thereby allowing more internal heat dissipation without
30 raising the operational temperature level of the equipment that is thermally coupled to the panels. One example, optical surface reflectors (OSRs), which have a

Therefore, by virtue of the present invention, the spacecraft could be operated at a higher efficiency, with higher reliability, and would thereby generate revenue at a faster rate, all of which improvements would increase
5 its value.

There is another important factor that affects the capability of a thermal radiator surface to reject heat to deep space: the "effective" radiative view factor
10 (ranging from 0 to 1) from that panel to deep space. The ideal radiative-view-factor enabling a panel to reject maximum heat into deep space is unity (1). A device or means situated between the radiator surface and deep space could block the radiator's view to deep space and
15 thus reduce the heat-radiating capability of the radiator.

The sun ray blocker device of this invention is mounted on the spacecraft, for example conveniently
20 attached to the solar array assembly/assemblies of the spacecraft and rotating therewith. Since the primary function of the sun ray blocker device used in this invention is to provide a significantly more benign thermal environment for the principal thermal radiator
25 surfaces (or panels), basically by shading them, the spacecraft should have at least one such surface. In the case of three-axis-stabilized Earth-pointing geostationary spacecraft, for example, there are two principal thermal radiator surfaces - the north and south
30 panels; and accordingly at least two separate sun ray blocker devices can be included, one to shade each of these panels. Thus, the sun ray blocker device in the

present invention follows the movement of the Sun with respect to the thermal radiator panel(s) that it shades. In the case of a three-axis-stabilized Earth-pointing geostationary spacecraft, like the model spacecraft for
5 example, the sun ray blocker device casts its shadow onto its associated thermal radiator surface, which is on either a north or a south panel, seasonally - through the six month long northern spring and summer in the case of the north panel, and through the six month long southern
10 spring and summer in the case of the south panel. The (counter-productive) reduction in the radiation-view-factor of the thermal radiator surface caused by the presence of the associated present invention device is small; and the net effect of this reduction combined with
15 the (beneficial) shading of the panel is a great improvement in the radiative efficiency of the radiator surface.

In addition to the foregoing, some of the
20 considerations, advantages and parameters for the present invention device are as follows (others will become self-evident from the subsequent discussion of the FIGURES):

Variety in the operational form and size of the sun
25 ray blocker device is permissible provided that its sun blocker panel follows the movement of the Sun with respect to the spacecraft, and it blocks the Sun's rays by casting a shadow onto the spacecraft main body at appropriate times, and it produces close to the minimum
30 reduction in the effective radiative view factor to deep space of the thermal radiator that it shields, and it

satisfies other system requirements of the spacecraft
(for example clear field of view requirements).

The material and/or the construction of the sun
5 blocker panel of the sun ray blocker device is preferably
highly thermally insulating between its sun and anti-sun
sides in order to provide the greatest practical
effective radiative view factor and radiative efficiency
of the radiator-surface shielded by the sun blocker
10 panel.

In its fully deployed configuration the sun blocker
panel may be mounted through a wide range of orientations
relative to the radiator surface that it shields (for
15 example, the angle 501 in FIGURE 12a below does not have
to be 90 degrees i.e. a right angle) as long as it casts
shadow providing adequate coverage of the associated
thermal radiator surface(s) on the spacecraft.

20 The ideal width of the sun blocker panel is greater
than either the width or the length of the radiator
surface that it shields. However, the dimensions of the
sun blocker panel may be limited by other constraints.
For example, in the launch configuration the folded
25 dimensions of the sun blocker panel may be limited by
launch-envelope constraints, i.e. the size of the volume
allowed for the spacecraft by the launch vehicle during
launch. Therefore, it may be necessary to make the sun
ray blocker panel deployable to enable it to be folded
30 for launch and deployed in orbit. This can be achieved by
hinged deployment, slide extension, pre-offset or any
other means to increase the width of the sun blocker

panel (see FIGURES 16a, b and c, and 17a, b and c discussed below).

5 The mechanisms for extending, deploying, and
supporting the sun blocker panel may involve various
techniques and devices that are well known in the current
state of the art of the design of mechanisms for
spacecraft. For example the techniques and devices
employed could involve mechanisms constructed from well
10 known device types such as: hinges, flaps, slides, spring
motors, wax motors, detentes, cable/bolt cutters, split
nut releases, pin pullers, hook and pin releases, etc.
Alternatively, so-called "active" devices such as
electrical motors may be used at the discretion of the
15 spacecraft designer. For example, one or more electrical
motor (for example a stepper drive motor) could be
employed to produce the motions resulting in extension
(and possibly also retraction) of the sun blocker panel.
Such active control could be utilized to facilitate
20 certain operations of the spacecraft, for example
station-keeping and attitude control operations for which
displacing the sun blocker panel from the exhaust plume
fields of rocket thrusters would be beneficial.

25 The present invention device is applicable to
spacecraft other than those spacecraft, like the model
spacecraft for example, which operate in the low-
inclination or equatorial orbits that have been described
thus far herein. It is applicable to the broad class of
30 spacecraft for which the solar illumination (insolation)
is incident at low angles relative to the planes of the
surface(s) of their thermal-radiator surface(s).

A certain subset of spacecraft belonging to the set of spacecraft that are well known in the space industry as "sun synchronous" fulfill this requirement for low
5 solar incidence angles on at least one thermal radiator surface; and the present invention is applicable to them. Within this subset of sun synchronous spacecraft is an even smaller but well known subset comprised of those spacecraft that operate in orbits with low orbit-Sun
10 angles and in which the thermal radiator surfaces are utilized while oriented close to parallel to the orbit plane. A sun ray blocker device according to this invention is applicable to those spacecraft, to provide them with a shaded, benign, and desirable thermal
15 environment for their thermal-radiator surfaces basically by protecting them against direct solar heating. Note, however, that when the angle of incidence of direct sunlight on the thermal radiator surface is zero the sun ray blocker device is unnecessary.

20

Heretofore the structural configuration and orientation of spacecraft to which the current invention device is applicable have mainly been described with reference to three-axis-stabilized Earth-pointing
25 spacecraft for operating in low inclination or equatorial orbits, like the model spacecraft for example. The fundamental difference between those preceding descriptions and the structural configurations and orientations of the sun synchronous spacecraft to which
30 the current invention device is applicable stems from the orientation of the orbit with respect to the axis of rotation of the planet. Within the space industry, sun

synchronous orbits are widely referred to as being "polar", since the orbit plane of a sun synchronous orbit, around Earth and Mars at least, lies within several degrees of the axis of rotation of the planet;
5 and therefore nominally includes the planetary poles. Therefore, for the aforementioned particular subset of sun synchronous spacecraft to which the current invention device is applicable, the panels and the radiator surfaces on them that are thermally protected by the
10 current invention device are generally not, strictly speaking, "north" and "south" panels. However, herein the terms "north" and "south" are occasionally used for convenience to indicate the panels that are thermally protected by the sun blocker panel on spacecraft in sun
15 synchronous orbits as well as on spacecraft like the model spacecraft, for example, in (nominally) equatorial orbits. The rationale is that in the particular, suitable, well known, and currently populous, aforementioned, subset of sun synchronous spacecraft the
20 planes of thermal radiator panels shielded by the present invention device are also approximately perpendicular to the axis of the orbit (as for spacecraft like the model spacecraft in its orbital configuration and orientation). For both these types of spacecraft we could instead
25 meaningfully refer to the protected panels and radiator surfaces as "pitch-axis" or "orbit normal" panels and surfaces, because the pitch axis of the spacecraft (which is parallel to the orbit normal) is nominally/approximately perpendicular to them and thereby
30 defines their orientation.

Depending upon the requirements of the propulsion subsystem and/or the attitude control subsystem of the spacecraft, the spacecraft designer may elect to provide only one sun ray blocker device, i.e. on only one of the
5 two sides of the spacecraft that face approximately along the pitch axis (e.g. on the north or the south panel for the model spacecraft). In any particular application there may be a preference for one side of the spacecraft over the opposite side because of other system
10 requirements. For example, in a potential embodiment of the present invention device on a particular current design of geostationary spacecraft, the south side is preferred because of field of view requirements for attitude-control thrusters on the north side.

15

Again, if the spacecraft designer elects to do so, solar cells can be mounted onto the external surfaces of the sun blocker panel to provide additional power to the spacecraft.

20

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention should be more fully understood when the specification herein is taken in
25 conjunction with the drawings appended hereto showing exemplary embodiments of the invention wherein:

FIGURE 1 is a simplified perspective view of a prior art three axis stabilized Earth-pointing geosynchronous
30 spacecraft;

FIGURE 2 shows an east-panel based view of the prior art spacecraft illustrated in FIGURE 1 orbiting in a low inclination or an equatorial orbit;

5 FIGURE 3a shows a north-panel based, top view of the prior art spacecraft illustrated in FIGURE 1 orbiting about the Earth at different times of the day, and FIGURE 3b illustrates orbit-plane based views of that spacecraft at its noon, 6 a.m., and midnight positions and also
10 establishes sun angles for different seasons of the year;

FIGURES 4a and 4b show the variation in the solar incidence angle on the north and south panels, respectively, of the prior art spacecraft illustrated in
15 FIGURE 1 orbiting Earth, through one calendar year;

FIGURE 5 illustrates a perspective view of a spacecraft configuration according to the present invention, based on the prior art spacecraft illustrated
20 in FIGURE 1;

FIGURES 6a, 6b and 6c illustrate top views of a present invention arrangement as applied to the prior art spacecraft illustrated in FIGURE 1. The views shown are
25 simultaneously parallel to both the orbit-plane and the plane of the solar cell panels and the sun blocker panels of the sun ray blocker device. Hereinafter this view direction is also referred to as "top view". FIGURES 6a, 6b and 6c show that as the spacecraft revolves around the
30 orbit the earth panel always faces the Earth, and the cell-side of the solar array panels together with the

front (sunward) sides of the sun blocker panels of the sun ray blocker devices always face the Sun;

FIGURES 7, 8 and 9 illustrate top views of present invention devices utilizing different attachment
5 arrangements;

FIGURES 10a, 10b and 10c illustrate portions of top views of one of the solar array assemblies of a prior art spacecraft before, during, and after its deployment;
10

FIGURES 11a, 11b, 11c, 12a, and 12b show, in top view, aspects of the deployment and the function of present invention devices as applied to the prior art spacecraft shown in FIGURES 10a, 10b, and 10c;
15

FIGURES 13 and 14a show partial top views of two alternative present invention devices; and FIGURE 14b shows a partial back (anti-sun) side view of the arrangement shown in FIGURE 14a;
20

FIGURES 15a and 15b show partial top views of an alternative present invention device in its fully deployed and partially deployed configurations, respectively;
25

FIGURES 16a, b, and c show a view of an alternative present-invention device from the front (sunward) direction with the sun blocker panel fully deployed, and two views from a direction orthogonal to both the front
30 view and the (previously defined) top view directions

with the sun blocker panel folded and deployed,
respectively;

FIGURES 17a, b, and c show a different alternative
5 present-invention device in the same views and deployed
states as those shown in FIGURES 16a, b, and c;

FIGURE 18 shows a further embodiment of the
invention;

10

FIGURE 19 shows another embodiment of the invention;

FIGURE 20 shows another embodiment of the invention;

15 FIGURES 21 to 24 and 26 show another embodiment of
the invention;

FIGURE 25 shows details of the embodiments of
FIGURES 21 and 24 and 26;

20

FIGURES 27 to 30 show another embodiment of the
invention; and

FIGURES 31 and 32 illustrate alternative shapes for
25 sun blocker panels used in the present invention.

Referring now to FIGURE 1, there is shown an oblique
view of a fully deployed (i.e. fully unfolded from its
launch configuration) spacecraft (or satellite) 1, like
30 the previously described model spacecraft for example,
which is represented by a main body 10 which contains six
external panels: 11, 12, 13, 14, 15 and 16, a group of

antenna reflectors 20, 21, 22 and 23, and two solar array assemblies, consisting of two solar arrays (one or more solar cell panel) 100 and 101 and their supports 100a and 101a by which they are connected to the main body 10, which are extended northward and southward from the main body out of the north and south panels 11 and 12, respectively. The number of antenna reflectors is driven by the need of the telecommunications application and is a matter of design. In this example, four reflectors are shown and are represented by two deployable large reflectors 20 and 21 mounted on east and west panels 15 and 16, respectively. Two non-deployable reflectors 22 and 23 are mounted on nadir panel 14. While orbiting in a low inclination orbit about Earth, the spacecraft is controlled in such a way that the earth or nadir panel 14 is pointing in the general direction of the center of the Earth, thus allowing the antenna reflectors to perform telecommunications functions with Earth. Opposite to the earth panel 14 is the zenith panel 13.

20

The solar arrays 100 and 101 may contain multiple panel elements (typically two to eight or more on each side - a four panel-element example is shown in FIGURE 1) or may contain as few as one panel element. However, usually solar arrays that are comprised of multiple solar cell panels are utilized, in order to provide sufficient electrical power for the spacecraft's use. The size and number of the solar cell panels is driven by mission power requirements, and is constrained by, among other factors, the capability of the attitude control subsystem to maintain pointing stability and also by the capability of the thermal control subsystem to manage the heat

for a portion of the calendar year. These periods are nominally 21 March through 21 September for the north panel, and 21 September through 21 March for the south panel. Therefore, the sun ray blocker devices of the
5 current invention perform their shading functions for their respective radiator panels for those periods only.

FIGURE 5 illustrates one preferred embodiment of the current invention, which eliminates or greatly reduces
10 the seasonal solar input on the north and south panels 11 and 12, thus providing more efficient thermal radiators for the spacecraft.

In this present invention embodiment, the sun ray
15 blocker devices are comprised of two sun blocker panels 111 and 112 and mounting, supporting, and deployment mechanisms by means of which the blocker panels are integrated with and deployed with the structures and mechanisms that support and cause the solar array to
20 rotate. The radiators on the north and south panels 11 and 12 have dedicated sun ray blocker devices 111 and 112 attached to the north and south array assemblies 100 and 101, respectively, as shown in FIGURE 5. After the thus modified spacecraft 1 has been launched into the
25 operational orbit and its appendages have been fully deployed, the sun blocker panels 111 and 112 will achieve their final positions in front of the cell side of the solar arrays with their surfaces more or less parallel to the plane of the solar arrays. The south blocker device
30 112 is positioned such that during the time between the northern autumnal and northern spring equinoxes, when otherwise there would exist a potential for solar heating

of the south panel 12, the south blocker device 112 will cast a shadow over the south panel 12 thereby eliminating the potential for such solar heating. The north blocker device 111 performs a similar function relative to the
5 north panel 11 during the time between the northern spring and northern autumnal equinoxes. When the solar array assemblies 100 and 101 are maintained directly sun pointed, by virtue of their being rotated, the sun blocker devices will likewise be maintained directly sun
10 pointed and thereby interposed between the Sun and the north and south panels that they shade.

The materials used for the sun blocker panels 111 and 112 are selected to minimize the heat transferred
15 from their sun facing surfaces 111a and 112a to their anti-sunward surfaces 111b and 112b. This may be achieved by including insulating material(s) and constructions in the composition of the sun blocker panels. For example, the panels may include known thermally insulating
20 materials and assemblies of materials, such as multi-layer insulation (MLI) blankets which utilize layered films of metallized Mylar separated by fabric netting. These materials and constructions are well known in the space industry and have typical heat resistance values of
25 0.007 to 0.01 Watt/deg.C/sq.in. The sun blocker panels of the present invention device will generally experience a sizable temperature difference, for example possibly greater than 100 degree C, between surface 111a and surface 111b and between surface 112a and surface 112b
30 when the satellite is in its normal orientation in the mission orbit, except when the spacecraft is passing through the Earth's shadow.

To obtain the maximum sun blocking effect, the panels of the sun ray blocker devices 111 and 112 are configured (sized, oriented, and positioned) in such a way that at the summer and winter solstices, when the Sun is about 23.5 degree from the orbit plane, the sun blocker devices will cast shadows that entirely cover the radiator surfaces on their respective thermal radiator surfaces on the spacecraft panels 11 and 12.

Accordingly, if the radiator surfaces are rectangular the shadows must be at least as wide as the diagonals of the rectangles.

FIGURES 6a, 6b and 6c show top partial views of a present invention arrangement as the spacecraft orbits Earth and the main body 10 is rotated at the orbital rate so that the earth panel 14 always faces Earth, and the sun blocker panels 111 and 112 always face the Sun (which is at the left in the FIGURES). These FIGURES are drawn in the inertial frame of reference of the solar array assemblies 100 and 101. Thus, if one were to stand on either of the solar array assemblies 101 and 102 one would see main body 10 rotate one revolution per orbital revolution around the Earth.

FIGURE 7 is a top partial section view showing more details of a present invention spacecraft. In this context the phrase "top view" denotes a view parallel to the planes of the sun blocker panels 111 and 112 and also parallel to the orbit plane. Note that in Figure 7 through Figure 15b various examples of embodiments of the present invention are depicted together with generic

partial views of a spacecraft main body and a solar array assembly (labeled 400 and 408, respectively, later in FIGURES 10 and FIGURES 11). Additionally, FIGURES 8 and 9 show alternative embodiment arrangements in top partial section views.

In FIGURE 7, the spacecraft has main body 10, north panel 11, and solar cell panel support 223 with attached solar cell panel 225. In this case, there is a connecting solar array boom-and-yoke 219 and hinges at hinge points 221 and 227. Together this solar cell panel support 223, a solar cell panel 225, a solar array boom-and-yoke 219, and the hinges at hinge points 221 and 227 comprise part of a solar array assembly. The solar array boom-and-yoke 219 fold forwardly against north panel 11 and the solar cell panel support 223 together with the solar cell panel 225 folds down at hinge point 227 in an accordion-like fashion for launching. During launch, ascent, and orbit achievement the solar array assembly is in its folded-closed configuration. After achievement of the mission orbit it is electro-mechanically and/or mechanically deployed (unfolded) to allow the solar cells to be maintained directly sun-pointed. Attached to solar cell panel support 223 is a two-section connecting arm having a short inner portion 209 and an outer portion 207 connected by hinge(s) at hinge point 215. The anti-sunward side 111b of sun blocker panel 111 is connected to outer arm portion 207 by hinge(s) at hinge point 203. Optional solar cells 201 are functionally positioned on the sunward surface 111a of the sun blocker panel 111. Hinge points 203 and 215 provide for folding of the solar blocker panel 111 and its hinged arm 207 against the

solar cell panel 225 in a compact and stiff configuration suitable for launch and subsequent deployment. The electromechanical and/or mechanical designs and methods for deploying (opening) and closing solar array assemblies are commonly used in contemporary spacecraft. The same or similar mechanisms are used to deploy the sun ray blocker devices of the present invention. These mechanisms and methods for deployment and closing are well within the skills of the artisan.

10

In FIGURE 7, there is an imaginary plane 250 extending off the surface of north panel 11. In its deployed configuration the sun blocker panel 111 may touch or extend through this imaginary surface, and consequently may provide additional shading for the earth, west, zenith and east panels as they rotate with respect to the Sun.

FIGURE 8 shows an alternative embodiment where sun ray blocker device 271 does not intersect imaginary plane 250. Further, it has a single connecting arm 205 with hinge points 203 and 217 at opposite ends to form an assembly and is connected directly to the substrate of solar cell panel 225. It may be folded and stowed for launch and deployed or unfolded in orbit in a similar way to the sun ray blocker device in FIGURE 7. In FIGURES 7 and 8, the sun ray blocker devices cast their shadows over the major part of the outer surface of north panel 11 and, in these embodiments, completely shadow that surface during the times when otherwise they would be exposed to the Sun. Further, the solar cells 201 may be

20
25
30

included to produce additional solar power for the spacecraft.

In FIGURE 9, identical parts to FIGURES 7 and 8 are
5 identically numbered. Sun ray blocker device 301 is
connected directly to solar cell panel support 223 by
hinge(s) at hinge point 309 so as to fold over up-close
against solar cell panel 225 in the launch configuration.
In this embodiment, sun ray blocker device 301 is not
10 parallel to the solar array, yet still effectively shades
north panel 11.

FIGURES 10a, 10b and 10c depict a typical prior art
sequence of deployment of a solar array assembly, which
15 is part of the transformation of the spacecraft from its
launch configuration to its configuration for normal
operations in orbit. For simplification in this
document, only one (the north) solar array assembly is
shown in the FIGURES. These particular FIGURES show a
20 satellite with a main body 400, and a solar array
assembly 408 comprised of four solar cell panels, with
solar cell surfaces 400a, mounted on solar cell panel
supports 408 which are interconnected by hinges at three
hinge points 403, 404, and 405 and connected to the main
25 body 400 by a single boom 419 and hinge(s) at hinge
points 401 and 402. FIGURE 10a depicts the solar array
assembly folded and stowed for launch. FIGURE 10b
depicts it in the process of being deployed (unfolded).
Figure 10c depicts its fully deployed state. If a
30 multiple-arm boom design is desired by the spacecraft
designer, various embodiments can be designed to satisfy

performance requirements using greater numbers of arms and hinge points.

FIGURES 11a, 11b and 11c illustrate the deployment
5 sequence of one possible design embodying the present
invention. Components in FIGURES 11a, 11b, and 11c that
are identical to components in FIGURES 10a, 10b, and 10c
are numbered identically to their identical parts. In
addition to the prior art solar array assembly that was
10 previously depicted in FIGURES 10a, 10b and 10c, FIGURES
11a, 11b, and 11c also depict the present invention sun
blocker panel 411 connected to the solar array boom 419
by an arm 430 and hinges at hinge points 406 and 407.
Alternatively, by design the sun blocker panel 411 could
15 be hingedly attached via the arm 430 to a convenient
different location on the solar array assembly. FIGURE
11a depicts the solar array assembly and the sun ray
blocker device folded and stowed for launch, FIGURE 11b
shows them partially deployed (unfolded). FIGURE 11c
20 depicts their fully deployed state. FIGURES 12a and 12b
show sun blocker panels which are not parallel to the
plane containing the solar cell panels yet which still
provide proper shading of the north or south panel.
Components in FIGURES 12a and 12b and subsequent figures
25 that are identical to components that appear in previous
figures are numbered identically with their corresponding
or very similar components or are left un-numbered to
avoid unnecessary repetition. Alternatively, by design
the sun blocker panel 111 could be hingedly attached via
30 the arm 430 to a convenient different location on the
solar array assembly.

FIGURE 13 depicts yet another alternative embodiment of the present invention. The sun blocker panel 511 is connected to the solar array boom 219 by hinge(s) at hinge point 507 for its stowing folded and subsequent
5 deployment.

FIGURES 14a and b show an arrangement similar to that in FIGURE 13, with identical parts identically numbered, however, more hinges at hinge points 606 and
10 607 are used with blocker panel 611 as required by design for folding the panels prior to deployment.

FIGURE 14b represents a partial view of the anti-sun side of the spacecraft looking toward the Sun (i.e. a
15 side view relative to the top view shown in Figure 14a).

FIGURES 15a and 15b show one embodiment in which sun blocker panel 811 utilizes separate active motors 306 and 307 which are used to actively deploy and/or retract the
20 sun ray blocker device. This arrangement allows satellite operators to use deployment motors that are separate from the solar panel deployment motors so as to permit them to retract the sun blocker panels to prevent their interference, if any, in satellite operations such
25 as in the use of propulsion systems during spacecraft performance of station keeping or attitude control maneuvers.

In some spacecraft designs the required size
30 (dimensions and/or area) of a sun blocker panel in its fully deployed configuration may exceed the constraints of its "launch envelope" i.e. the constraints of the

maximum-allowable space allocated to the sun ray blocker device in the launch configuration of the spacecraft when the solar array and the sun ray blocker device are in their launch configuration. Therefore, for compatibility
5 with the constraints of the size of the corresponding launch envelope it may be necessary for the sun blocker panel of the sun ray blocker device to be comprised of several (i.e. more than one) pieces, instead of being one single integral piece, which are folded together in the
10 launch configuration and are subsequently deployed (unfolded) in orbit to form effectively one continuous sun blocker panel. FIGURES 16a, 16b and 16c, and FIGURES 17a, 17b and 17c, respectively depict two examples from the many possible designs for sun blocker panels which
15 fold and deploy. Parts a, b, and c of the FIGURES 16 and 17 show each of the two designs in a view from the front (Sun) direction with the sun blocker panel fully deployed, and two views from a direction orthogonal to both the front view and the top view directions with the
20 sun blocker panel folded and deployed, respectively. (As defined earlier herein the phrase "top view" denotes a view that is simultaneously parallel to the plane of the sun blocker panels 921 or 951 and the orbit plane.) This allows the sun ray blocker device to increase its
25 dimensions using hinge(s) and/or strut(s) and/or flap(s) etc. at hinge points 925 and 927 or a slide-out design. Referring collectively to all FIGURES 16, sun blocker panel 921 has a center section 923 with hinge(s) and/or strut(s) and/or flap(s) etc. at hinge points 925 and 927
30 and outer, swing up panels 929 and 931 which may be designed to deploy (swing up) automatically. In all FIGURES 17, sun blocker panel 951 has main section 953

with slide-out extensions 955 and 957 that may be designed to deploy (slide out) automatically. (Automatic hinging and automatic sliding or telescoping is well within the purview of the artisan in the spacecraft
5 industry and need not be further elaborated upon herein.)

The embodiments of the present invention device illustrated in FIGURES 18 through FIGURE 30 are as generally applicable as the other embodiments described
10 herein. However, they also function efficiently in cases where a sun blocker device cannot be attached to an axle located near the center (1811, 2123, 2722) of an associated thermal radiator surface (1804, 2121, 2721).

15 One such case is that in which the axis of rotation (1803, 2131, 2701) of a solar array assembly extends outward from the associated thermal radiator surface (1804, 2121, 2721) at a location that is significantly offset from the center (1811, 2123, 2722) of the thermal
20 radiator surface. In that case, designs with an attachment arm of fixed length between the sun blocker panel and the solar array axis could be unsuitable, because the motion of the sun blocker panel about the center of the thermal radiator surface would be
25 eccentric.

Another such case is that in which there are stay-out zones inboard of the periphery of the associated thermal radiator surface - through which objects such as
30 a supporting boom (for example for a sun blocker panel) are not allowed to pass. This could be the case, for example, when certain attitude- or orbit- control

thrusters (1810) are also located on the panel upon which the thermal radiator surface (1804) is located.

5 The arrangements illustrated in FIGURES 18 through
FIGURE 30 may be employed to overcome these constraints,
whilst still maintaining a sun blocker panel at a
substantially uniform distance from the center of the
associated thermal radiator surface. Selection between
the embodiments shown in FIGURES 18-30 for any particular
10 application may involve trade-offs between many
additional performance-requirements of the spacecraft-
system, including for example: mass, strength, stiffness,
flatness, circularity, simplicity, and reliability.

15 Figure 18 shows an embodiment of a sun blocker
device in which the sun blocker panel 1800 is mounted on
a carriage 1801 with wheel-sets or bearing-sets 1808 and
1830 by means of an attachment arm 1805 in which the
carriage may be driven around a closed rail 1802, the
20 carriage 1801 being attached to the rail 1802 by rolling
or sliding means that also react against and thereby
limit rotations of the carriage 1801 (and thereby the sun
blocker panel) about axes passing through the points of
contact of the carriage and the rail. In one of many
25 potential embodiments, for example, this may be achieved
using wheel or bearing sets 1808, 1830 that are
adequately spaced both along-track and cross-track on
both sides of the rail 1802, and which are also cambered
at an adequate angle to the plane of the baseplate.
30 Attached to the carriage is at least one generally-radial
boom or strut 1805, an outer end of which is attached to
the sun blocker panel at hinge point 1812 and an inner

guide

end of which is attached to the carriage 1801 at hinge-point 1813, and the carriage is rollingly or slidingly mounted on the rail 1802 by the wheels or bearings 1808 and 1830. At least one of these wheels 1830 or bearings is provided with a motor to drive the carriage along the rail 1802, for example by friction, or by the engagement of a toothed wheel or a worm-drive in a rack. Electrical power may be supplied to the motor, via brushes for example. The attachment arm 1805 and the sun blocker panel 1800 can be folded at the hinge points 1812 and 1813 to achieve a stowed configuration of the sun blocker device for launch, during which the folded device may be temporarily caged securely for proper management of launch-induced dynamic environments and loads. The sun blocker panel may be further folded for launch as illustrated in FIGURES 16 and 17. Following launch the attachment arm 1805 and the sun blocker panel 1800 can be deployed for subsequent operation in orbit, including sun-tracking travel around rail 1802. It will be appreciated that the rail 1802 need not be circular as shown in FIGURE 18, but in the case of a significantly rectangular thermal radiator surface, for example, the rail could be elliptical and in either case may be diverted to avoid obstacles mounted on the spacecraft.

Alternatively, as illustrated in FIGURE 19 the attachment arm ~~1805~~ could be mounted on a solid rotatable wheel instead of on a carriage and rail. In the embodiment illustrated in FIGURE 19 the wheel is a ring or annulus 1902 floating in circumferentially located bearing-sets 1903 and controlled and driven by a motor 1930 mounted on the baseplate under 1804.

1901 (shown composed of elements for example by an internal structure by attachments, 1906, 1927)
1905
guide

In a similar alternative embodiment, illustrated in FIGURE 20, a carriage 2001, similar to that provided in the embodiment illustrated in FIGURE 18, is provided; but
5 in this embodiment the carriage 2001 is driven around a closed rail 2002 not by a motorized wheel, but by an endless belt 2003, chain, or cable attached to the carriage 2001, the belt being driven by a motor 2030 that is mounted to the baseplate under 1804 and which engages
10 the belt 2003, chain, or cord. A tensioning device 2040 is also provided to engage the belt 2003 and tension the belt while not impeding the passage of the carriage around the rail 2002. Again, as in the embodiment illustrated in FIGURE 18 the rail 2002 need not be
15 circular.

Figures 21 through 30 illustrate embodiments in which a sun blocker panel is mounted on the spacecraft via an attachment arm from an axis 2131, 2701 that is
20 offset from the center 2123, 2722 of an associated thermal radiator surface. The axis 2131, 2701 could be concentric with or identical to the axis of rotation of a solar array assembly.

25 Figures 21 through 26 illustrate an alternative embodiment in which a sun blocker panel 2100 is attached to an axle at axis 2131. The axle may be either concentric with or identical to an axle of a solar array assembly. The sun blocker panel is attached to the axle
30 by an articulated attachment arm 2130 that included three articulated portions 2132, 2134, 2137.

The inner end of the inner-portion 2132 is fixed radially to the axle at axis 2131. The middle-portion 2134 is pivoted at its inner end to inner-portion 2132 at pivot-point 2133, and the outer end of middle-portion 2134 is pivoted to the inner end of outer-portion 2137 at pivot point 2135. At its outer end the outer-portion is attached to the sun blocker panel at hinge point 2138 and near its inner end the outer-portion is hinged at hinge point 2136 to allow folding and stowing for launch followed by deployment in orbit.

As depicted in FIGURE 21 through FIGURE 26 the inner-portion 2132 and the outer portion 2137 of the attachment arm 2130 turn anti-clockwise at the same rate, the outer-portion 2137 carrying the sun blocker panel with it, whereas the middle portion 2134 rotates clockwise at the same rate.

The length of the inner-portion 2132 is approximately equal to the offset of the axis of rotation 2131 from the center 2123 of the thermal radiator surface. In principle the length of the middle-portion 2134 may be longer or shorter than the length of the inner portion 2132. However, in the case that the axis of rotation 2131 is occupied by an obstruction such as the axle of a solar array assembly then the middle-portion 2134 must be shorter than the inner-portion 2132 for clearance of the solar array axle at axis 2131, as can be seen in FIGURE 23 in which the attachment arm 2130 is approaching its closest to the axle at axis 2131.

By articulating the articulated portions through rotation of the arm 2130 about the axis of rotation 2131 the sun blocker panel can be maintained at a substantially constant distance from the center of the associated thermal radiator surface 2121, to describe a substantially circular path 2140 around the spacecraft. It will be evident that in the case of a thermal radiator surface that is significantly far from being radially symmetric the length of the articulated portions of arm 2130 could be adapted to achieve a wide range of desired paths around the thermal radiator surface.

As shown in FIGURE 21, the articulated portions 2132, 2134, 2137 are arranged to the full reach of attachment arm 2130 in a straight line when the sun blocker panel is passing a side of the thermal radiator surface furthest from the axis of rotation 2131. As shown in FIGURES 22 and 23 the attachment arm 2130 has an effective length equal to the sum of the lengths of an outer 2137 and an inner 2132 articulated portion when the sun blocker panel 2100 is at an intermediate distance from the axis of rotation 2131. As shown in FIGURE 23, the effective length of the attachment arm 2130 is at its minimum when the sun blocker panel is at its closest to the axis of rotation 2131, at which point its length is equal to the sum of the lengths of the inner 2132 and outer 2137 portions less twice the length of the middle-portion.

The inner articulated portion 2132 of the attachment arm 2130 rotates about axis 2131. The means of attachment of the inner articulated portion 2132 may be

as the inner articulated portion 2132 whereas the middle articulated portion 2134 counter-rotates.

In a further embodiment illustrated in FIGURES 27
5 through 30, a sun blocker panel 2700 is attached to an
axle 2701 of a solar cell array by means of a scissor
attachment arm 2730. The scissor arm is comprised of a
first articulated arm 2704, 2708 and a second articulated
arm 2705, 2709, comprised of inner articulated portions
10 2704, 2705 and outer articulated portions 2708, 2709
respectively. The inner articulated portions are
connected by hinges at hinge points 2702, 2703 to the
solar array boom 2701 respectively and the outer ends of
the outer articulated portions 2708, 2709 are connected
15 by hinges 2710, 2711 to the sun blocker panel 2700 such
that when the articulated arms are extended to the full
length they are still not parallel to avoid their locking
up. A lanyard 2712 is located in between the articulated
arms 2704, 2708 and 2705, 2709 and extends between the
20 sun blocker panel 2700 and the solar array axle 2701.
The inner articulated portions 2704, 2705 and the outer
articulated portions 2708, 2709 are sprung at hinge
points 2706 and 2707 so as to automatically extend the
articulated arms 2704, 2708 and 2705, 2709 to their full
25 extent as limited by the lanyard control. The
articulated arms 2704, 2708 and 2705, 2709 thereby form a
parallelogram, the shape of which may be controlled by
retracting or deploying the lanyard 2712. Alternatively
the shape of the parallelogram could be controlled by
30 motorized hinges, or alternatively by a retractable and
deployable lanyard between hinge points 2706 and 2707
with sprung hinges 2702, 2703, 2710 and 2711 instead of

at 2706 and 2707. In the embodiment of the invention illustrated in FIGURES 21 through 24, the distance of the sun blocker panel 2700 from the solar array boom 2701 can be varied as the sun blocker panel 2700 rotates about the
5 solar array boom 2701 to maintain the sun blocker panel at a constant distance from the spacecraft as illustrated by the path 2712.

The embodiments described in FIGURES 18 through 20
10 have the advantage that the attachment arm does not obscure thrusters 1810 present on the face of the spacecraft, that the sun blocker panel shades.

A sun blocker panel 3100, 3200 is not necessarily
15 rectangular in shape. As shown in FIGURE 31, the sun blocker panel 3100 has trapezoidal first-and second-extensions 3101, 3102 hingedly attached to a main body 3103 of a sun blocker panel 3100. The first extension 3101 is extended by unfolding the extension through
20 rotation in the direction of the arrows 3104 and the second extension is extended by unfolding the extension through rotation in the direction of the arrows 3105 from a position flat against the main body 3103.

25 As shown in FIGURE 32 a rectangular main body 3202 of the sun blocker panel 3200 may have substantially triangular extensions 3201, 3202 which may be extended and retracted from the main body by sliding translation of the extension 3201 in the direction of double-handed
30 arrow 3204 and unfolding the extension 3202 in the direction of arrows 3205.

The descriptions of designs for the structural support and the deployment of sun ray blocker devices written herein are examples from thousands of possible structural support and deployment designs which can be
5 used for this purpose and are within the scope of the present invention.

This paragraph describes an example to demonstrate the geometrical approach to calculating the dimensions of
10 a sun blocker panel for providing total shadow coverage to a quasi-rectangular shaped radiator surface. The example used is that of a radiator surface on a north or south panel of a geostationary spacecraft, like the previously defined "model" spacecraft for example, at the
15 summer or winter solstice, when the incidence angle of the Sun's rays (measured from the plane of the benefited thermal radiator surface) is at a maximum, using a quasi-rectangular (for this simple illustration at least) shaped sun blocker panel whose plane is perpendicular to
20 the plane of the associated thermal radiator surface (referring to FIGURE 12a, angle 501 is then 90 degree). For this example, take the north or south radiator-surface of the spacecraft to be rectangular, of length and width A and B, respectively. Then, the length and
25 width dimensions, L and W, respectively, of the sun-exposed surface of the fully-deployed sun blocker panel (which is shown in FIGURES 16a and 17a) should be as follows: L is greater than or equal to $\sqrt{A^2+B^2}$, and W is greater than or equal to $0.435 \times \sqrt{A^2+B^2}$ based on the
30 corresponding orbit-sun angle of 23.5 degree. However, if only a portion of the surface area on the north or south panel needs to be shadowed, i.e. high heat-dissipating

equipments were to be mounted in certain localized areas of the north or south panel, the sun ray blocker device can be tailored to shade only those areas and may accordingly be smaller. In addition, if a sun blocker panel whose plane is not perpendicular to the plane of the associated thermal radiator surface were to be selected by the spacecraft designer, the minimum value of the width, W , may be greater or less than $0.435 \times \sqrt{A^2+B^2}$ depending on the size of angle 501 in FIGURE 12a. If angle 501 is greater than 90 degree, W may be greater than $0.435 \times \sqrt{A^2+B^2}$; if it is less than 90 degree, W may be less than $0.435 \times \sqrt{A^2+B^2}$. If additional shading to the other four panels, earth, zenith, east and west panels, is desired, the width (W) of the sun blocker panel can be increased to extend past the imaginary plane 250 toward the center of the satellite as shown in FIGURE 7.

Thus, by the foregoing descriptions contained herein it can be seen that by virtue of the present invention losses in the efficiency of the cooling of the thermal radiator panels of a spacecraft caused by solar heating can be eliminated or minimized via various sun blocking arrangements.

25

Obviously, numerous modifications to and variations on the present invention are possible in light of the above teachings. For example, as a practical matter, a designer might counterweight or counterbalance the rotating axles or arms to overcome the weight imbalance caused by sun ray blocker devices of the present invention without exceeding the scope of the present

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invention. It is therefore understood that within the scope of the appended claims, the invention may be practiced otherwise than as specifically described herein.

CLAIMS

1. A spacecraft for orbiting a sunlit celestial body (300), the spacecraft including a thermal radiator surface (11,12,1804, 2121, 2721) for radiating heat
5 from the spacecraft into space, and a sun ray blocker device (111,112, 141, 271, 301, 411, 511, 611, 811, 921, 951,1800,2100, 2700) mounted on said spacecraft for shielding said thermal radiator surface (11,12,1804,2121,2721) from rays of sunlight,
10 characterised in that said sun ray blocker device is locatable for placing in shadow substantially the whole of the thermal radiator surface (11,12,1804,2121,2721) from sunlight without substantially impeding thermal radiation from said thermal radiator surface
15 (11,12,1804,2121,2721) into space.
2. A spacecraft as claimed in claim 1, wherein an effective radiation view factor for thermal radiation from the thermal radiator surface (11,12,1804, 2121,2721) to deep space is significantly greater than
20 corresponding geometrical radiation view factor to deep space, and in particular, for a geostationary spacecraft where the geometrical radiation view factor to deep space is 0.65, the effective radiation view factor to deep space is at least 0.87.
- 25 3. A spacecraft as claimed in claims 1 or 2, wherein the sun ray blocker device includes at least one sun blocker panel (111, 112) having a sun-facing surface (111a, 112a) and an opposed anti-sun-facing surface (111b, 112b), wherein the sun-facing surface (111a,

112a) is thermally insulated from the opposed surface (111b, 112b).

4. A spacecraft as claimed in claim 3, wherein the sun-facing surface (111a, 112a) is thermally insulated from the opposed surface (111b, 112b) by a multi-layer insulation blanket.
5. A spacecraft as claimed in claims 3 or 4, wherein the sun-facing surface (111a, 112a) has a low solar energy absorptivity of less than 0.5.
- 10 6. A spacecraft as claimed in any of claims 3 to 5, wherein the sun-facing surface (111a, 112a) includes a solar cell panel for supplying electrical power to the spacecraft.
- 15 7. A spacecraft as claimed in any of claims 3 to 6, wherein the sun-facing surface (111a, 112a) has a high thermal emissivity of higher than 0.7.
- 20 8. A spacecraft as claimed in any of claims 3 to 7, wherein the sun ray blocker device (111, 112, 141, 271, 301, 411, 511, 611, 811, 921, 951, 1800, 2100, 2700) is moveable between a stowed, non-operative position and a deployed operative position.
- 25 9. A spacecraft as claimed in any claims 3 to 8, wherein the sun ray blocker device (111, 112, 141, 271, 301, 411, 511, 611, 811, 921, 951, 1800, 2100, 2700) includes an attachment arm (207, 205, 430, 230) for attaching the sun blocker panel (111, 112) to the spacecraft.

10. A spacecraft as claimed in claim 9, wherein the attachment arm (207, 205, 430, 230) is attached by a hinge means(406, 306) to the sun blocker panel (111, 112) and/or by a second hinge means(407, 507, 607, 307) to the spacecraft.
11. A spacecraft as claimed in any of claims 8 to 10, wherein the sun ray blocker device (111,112; 141; 271; 301; 411; 511; 611; 811; 921; 951) includes a motor for moving the sun ray blocker device (111,112; 141; 271; 301; 411; 511; 611; 811; 921; 951) between the stowed position and the deployed position.
12. A spacecraft as claimed in any of claims 3 to 11, wherein locating means are provided for locating the sun ray blocker device (111,112; 141; 271; 301; 411; 511; 611; 811; 921; 951) with respect to the thermal radiator surface (11,12) which includes adjustment means to maintain the majority of the thermal radiator surface (11,12) in shadow irrespective of changes in the attitude and/or orbit of the spacecraft during normal operations.
13. A spacecraft as claimed in claim 12, wherein the adjustment means includes a variable length attachment arm (2130, 2730)for attachment of the sun blocker panel to the spacecraft.
14. A spacecraft as claimed in claim 13, wherein the attachment arm is a scissor arm (2730).
15. A spacecraft as claimed in claim 13, wherein the attachment arm (2130)is formed of articulated portions (2132, 2134, 2137) which may be mutually articulated

15. A spacecraft as claimed in claim 13, wherein the transport means includes rail means (2002) and belt means (2003) connected to the carriage means (2001), the belt means being driven by drive means (2030) to
5 move the carriage means along the rail means (2002).

16. A spacecraft as claimed in claim 13, wherein the carriage means includes an annulus (1920) rotatable in a circular path defined by bearing means (1903) the annulus being driveable by drive means (1930) to move
10 the carriage along the path defined by the bearing means.

17. A spacecraft as claimed in any of claims 12 to 16, having a solar cell array (100, 101, 408) adapted for tracking movements of the Sun relative to the
15 spacecraft, wherein the adjustment of the location of the sun ray blocker device (111, 112, 141, 271, 301, 411, 511, 611, 811, 921, 951) in relation to the thermal radiator surface (11, 12, 1804, 2121, 2721) is synchronised with the tracking movement of the solar
20 cell array, when in normal operation.

18. A spacecraft as claimed in claim 17, wherein the sun ray blocker device (111, 112; 141; 271; 301; 411; 511; 611; 811; 921; 951) is mounted on the solar cell array (100, 101 408) or on means carrying said solar cell
25 array.

19. A spacecraft as claimed in claim 18, wherein the solar cell array tracks the movement of the Sun by rotation of the solar cell array about an axis of rotation of the solar cell array (100, 101, 408) such

that the sun blocker panel (111, 112) also rotates about said axis of rotation of the solar cell array.

20. A spacecraft as claimed in claim 19, wherein the thermal radiator surface (11,12) is orthogonal to the axis of rotation of the solar cell array so that the sun blocker panel (111, 112) rotates about an axis normal to the thermal radiator surface.
21. A spacecraft as claimed in claim 18-20, wherein the adjustment means includes a variable length attachment arm (2130, 2730) for attachment of the sun blocker panel to the spacecraft.
22. A spacecraft as claimed in claim 21, wherein the attachment arm is a scissor arm (2730).
23. A spacecraft as claimed in claim 21, wherein the attachment arm (2130) is formed of articulated portions (2132, 2134, 2137) which may be mutually articulated during rotation to vary an effective length of the attachment arm.
24. A spacecraft as claimed in any of claims 21-23, wherein the adjustment means for attachment of the sun blocker panel (2100, 2700) to a solar cell array assembly (2131, 2701) are such that a distance between the sun blocker panel from the solar cell array assembly (2130, 2730) may be varied during rotation of the sun blocker panel.
25. A spacecraft as claimed in any of claims 3 to 24, wherein means (929, 931, 955, 957) are provided for adjusting the size of the sun blocker panel (111, 112).

26. A spacecraft as claimed in any of the preceding claims, including control means for controlling the spacecraft so as to maintain an angle between a sun line and the thermal radiator surface (11,12) below a
5 predetermined angle by adjustment of the orbit and/or attitude of the spacecraft in use.
27. A spacecraft as claimed in claim 26, wherein the predetermined angle is 60 degrees.
28. A spacecraft as claimed in claims 26 or 27, wherein
10 the control means is adapted to maintain the thermal radiator surface (11,12) substantially parallel to a plane of an orbit of the spacecraft.
29. A spacecraft as claimed in any of claims 26 to 28,
15 wherein the control means is adapted to maintain the spacecraft in a sun synchronous orbit.
30. A spacecraft as claimed in any of claims 26 to 28,
wherein the control means is adapted to maintain the spacecraft in an equatorial or low-inclination orbit.
31. In a three axis stabilised spacecraft for orbiting
20 about a planet and having at least one solar cell assembly having at least one solar cell panel, and being a north solar cell panel assembly or a south solar cell panel assembly, said at least one solar cell
25 panel assembly being mounted on an axle so as to be controllably rotated from said spacecraft about an axis of rotation so as to face the Sun, said spacecraft having a nadir panel which is generally pointing to the centre of the planet, an opposite panel known as a zenith panel, which faces away from the centre of the

planet and sharing the same planar normal vector as said nadir panel, an east panel and a west panel, said east panel and said west panel having their planar normal vector laying on a orbital plane pointing to the velocity vector of the spacecraft generally tangential to the direction of travel on the orbit, and a north panel and a south panel, said north panel and said south panel having their planar normal vector generally perpendicular to the orbit plane and parallel to the axis of rotation of the planet, said solar cell panel extending outwardly from said spacecraft, the improvement which comprises:

attaching at least one sun ray blocker device to said at least one solar cell panel, said at least one device being either a north blocker device or being a south blocker device and corresponding to said at least one solar cell panel, each of said at least one sun ray blocker device being positioned forwardly from and offset relative to a solar cell surface of a solar cell panel and at a predetermined angle to either of said north panel and said south panel, said north panel or said south panel, said sun ray blocker device being positioned so as to cast a shadow on at least a majority of the exposed surface of its corresponding north or south panel during solar exposure thereto.

32. In a three axis stabilised low inclination orbit spacecraft for orbiting about the earth and having two sets of solar cell array assemblies having solar cell arrays, one set being a north solar array assembly and the other being a south solar array assembly, said assemblies each being mounted on an axle so as to be

controllably rotated from said spacecraft about an axis of rotation so as to face the Sun, said spacecraft having an earth panel which is generally pointing to the centre of the earth, an opposite panel known as a zenith panel, which faces away from the centre of the earth and sharing the same planar normal vector as said earth panel, an east panel and a west panel, said east panel and said west panel having their planar normal vector laying on an orbital plane pointing to the velocity vector of the spacecraft generally tangential to the direction of travel on the orbit, and a north panel and a south panel, said north panel and said south panel having their planar normal vector generally perpendicular to the orbit plane and parallel to the axis of rotation of the earth, said solar cell panel extending outwardly from said spacecraft, the improvement which comprises:

attaching at least one sun ray blocker device to each of said north solar array and said south solar array, one device being a north device and another device being a south device, each of said sun ray blocker devices being in the form of a panel and being positioned forwardly and offset relative to the solar cell surface of a solar ray and at a predetermined angle to said north panel and said south panel, said north blocker device being positioned so as to cast a shadow on at least a majority of the exposed surface of said north panel during solar exposure thereto, and said south blocker device being positioned so as to cast a shadow on the exposed surface of said south panel during solar exposure thereto.

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and rotatable therewith. Thereby, the shading device will always be disposed between the Sun and the de-spun platform. However, the shading device also blocks thermal radiation from the platform and also itself heats up in sunlight and radiates heat towards the platform, decreasing the efficiencies of heat transfer from the spacecraft to space.

European Patent Application 98401320.1 by
Aerospatiale Societe Nationale Industrielle describes a satellite comprising a face used as a thermal radiator (i.e. a radiator-face) for equipment on board and lying in the path of solar radiance, a solar panel electric generator constantly oriented towards the Sun and projecting from the centre of the radiator-face, and a screen at the edge of the satellite fixed to the solar panel by a connecting arm and stopping the solar radiance directed towards the radiator-face. The screen reduces variations in temperatures of the radiator-face. Alone, however, coatings on the exterior of the screen are inadequate to prevent the screen from heating up in sunlight and radiating significant heat towards the radiator-face. Consequently, the effective radiation view factor of the radiator-face to deep space is significantly limited, the efficiencies of heat transfer from the radiator-face to space are limited, and temperatures of the radiator-face and the equipment on board are unduly high.

For discussions of radiation view factor and related factors see, for example, pp. 202-234, "Principles of

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Heat Transfer", Frank Kreith, Second Edition, University
of Colorado, 1965, and p. 426, "Principles of

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Communication Satellites", Gary D. Gordon and Walter L. Morgan, John Wiley and Sons, Inc., 1993.

5 European Patent Application 87402281.7 by Centre
Nationale d'Etudes Spatiale describes a device for a
geostationary satellite comprising a screen fixed on a
crown rotated by a motor-driven pinion so as to orient
the screen towards the Sun and protect a radiator used to
cool detectors of infrared instruments. The curvature
10 and extent of the screen, however, significantly limit
the effective radiation view factor of the radiator to
deep space, raising the temperatures of the radiator and
detectors unduly.

15 European Patent Application EP 91301447.8 by GEC-
Marconi Limited describes a geostationary satellite
comprising a pair of solar panels extending therefrom,
the planes of the panels lying parallel to the axis of
rotation of the satellite when in orbit. The solar
20 panels are offset with regard to an axis of rotation of
the satellite passing through the centre of mass of the
satellite. Attached to each solar panel is a blanking
plate, substantially co-planar with the solar panel and
extending to a plane containing the face of the satellite
25 from which the solar panel is supported. Optionally,
side panels (also blanking plates) may also be attached
along the north-south edges of the solar panels. The
solar panels, blanking plates, and side plates provide
masking of the Sun's rays for the faces of the satellite
30 on which the solar panels are mounted. The masking of
the Sun reduces the variations in temperatures of the
shaded panels. The solar panels, however, are heated by
the Sun and radiate heat towards the shaded panels,

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decreasing the efficiencies of heat transfer from the shaded faces to space, and raising the average temperature of the shaded faces and the equipment on board. Furthermore, since solar arrays have relatively
5 high mass, the offsetting of their centres of mass from their axes of rotation poses substantial difficulties, related to varying system mass-properties, in design of the satellite system.

10 United States Patent 5,527,001 to Teledesic Corporation describes a modular communication satellite comprising a solar array that completely shades the rest of the satellite from the Sun in operation in orbit. The
15 masking of the Sun reduces the variations in temperatures of the rest of the satellite. The solar array, however, is heated by the Sun and radiates significant heat towards the rest of the satellite, decreasing the efficiencies of heat transfer from the rest of the spacecraft to space, and raising the average temperature
20 of the rest of the spacecraft unduly.

Notwithstanding the prior art, the present invention is neither taught nor rendered obvious thereby.

25 It is an object of this invention substantially to reduce or eliminate the direct and indirect solar heating of certain spacecraft radiator-panels, and to also minimize the magnitude of any reduction in the radiation view factor of the (shielded) radiator panel to deep
30 space. In order to achieve that objective, the materials and design selected for the sun ray blocker device, which will be discussed below, should ideally provide all of the following: minimum blockage of the field-of-view to

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deep space of its associated radiator surface(s), low
absorption of the solar energy incident on its front
(sunward) surface, high radiation of absorbed thermal
energy back to space, and high insulation of heat between
5 the front (sunward) and back (anti-sunward) sides of the
sun ray blocker device.

It is also desirable to provide a sun ray blocker
device that is capable of greatly reducing or eliminating
10 solar energy incident on those sides of certain

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spacecraft relative to which the Sun direction makes a low angle. The types of spacecraft to which the present

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invention applies include some spacecraft for operation in equatorial or low inclination orbits, and in sun synchronous orbits with low orbit-sun angles. In the case of three-axis stabilized, Earth-pointing, geostationary spacecraft for example, these shaded sides are either or both of the north and south main-body panels. In the case of the sun synchronous spacecraft for example, the shaded sides are either or both of the sides or main-body panels that face out along the pitch axis (i.e. that face parallel to the orbit normal and anti-normal). The present invention can also be applied to types of spacecraft, other than geostationary and sun synchronous types, upon which the solar illumination is incident at low angles relative to thermal radiator surface. In those spacecraft it is those main thermal radiator surface that can be shaded by the present invention device.

According to a first embodiment of the invention there is provided a spacecraft for orbiting a sunlit celestial body, the spacecraft including a thermal radiator surface for radiating heat from the spacecraft into space, and a sun ray blocker device mounted on said spacecraft for shielding said thermal radiator surface from rays of sunlight, characterised in that said sun ray blocker device includes at least one sun blocker component, said sun blocker component being locatable, in an operational configuration, on a sun line from said thermal radiator surface and being of suitable shape, size, and orientation for placing in shadow up to the whole of said thermal radiator surface from sunlight, said sun blocker component having a surface intended to face the Sun in use and an opposed surface intended to

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face away from the Sun in use, said sun blocker component being adapted for achieving a high radiation view factor from the thermal radiator surface to deep space by means including thermal insulation material located between the sun-facing surface and the opposed surface for restricting heat flow through said sun blocker component between said sun-facing surface and said opposed surface.

Conveniently, the sun-facing surface is thermally insulated from the opposed surface by multi-layer insulation (MLI).

A preferred inventive feature will be seen to reside in said sun blocker component being further adapted for achieving a high radiation view factor from the thermal radiator surface to deep space by means including a region of said opposed surface being adapted to lie, in an operational configuration, substantially in a plane for limiting a radiation view factor from said opposed surface to said opposed surface.

A preferred inventive feature will be seen to reside in said sun blocker component being further adapted for achieving a high radiation view factor from the thermal radiator surface to deep space by means including a region of said opposed surface being adapted to face, in an operational configuration, at an angle away from said thermal radiator surface for limiting reflection by said sun blocker component of thermal energy from said thermal radiator surface back to said thermal radiator surface.

A preferred inventive feature will be seen to reside in said sun blocker component being further adapted for achieving a high radiation view factor from the thermal radiator surface to deep space by means

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including a dimension and/or a shape of said sun blocker component, in an operational configuration, serving to limit a corresponding geometric radiation view factor from said thermal radiator surface to deep space.

5 Preferably an effective radiation view factor for thermal radiation from the thermal radiator surface

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(11,12,1804, 2121,2721) to deep space is significantly greater than a corresponding geometrical radiation view factor to deep space, and in particular, for a geostationary spacecraft where the geometrical radiation view factor to deep space is 0.65, the effective radiation view factor to deep space is at least 0.87.

Advantageously the sun-facing surface has a low solar energy absorptivity of less than 0.5.

Advantageously the sun-facing surface includes a solar cell panel for supplying electrical power to the spacecraft.

Preferably the sun-facing surface has a high thermal emissivity of higher than 0.7.

A preferred inventive feature will be seen to reside in the sun ray blocker device being adapted for a re-configuration involving movement between a stowed, non-operative position and a deployed, operative position after launch of the spacecraft.

Conveniently the sun ray blocker device includes an attachment arm for attaching the sun blocker component to the spacecraft.

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Advantageously the attachment arm is attached by a hinge means to the sun blocker component and/or by a second hinge means to the spacecraft.

Advantageously the sun ray blocker device includes a
5 motor for moving said sun ray blocker device between the stowed position and the deployed position.

Preferably locating means are provided for locating the sun ray blocker device with respect to the thermal radiator surface which include adjustment means to
10 maintain up to the whole of the thermal radiator surface in shadow irrespective of changes in the attitude and/or orbital position and/or orbit of the spacecraft.

A preferred inventive feature will be seen to reside in the adjustment means including a variable length
15 attachment arm for attachment of the sun blocker component to the spacecraft.

Advantageously the attachment arm is a scissors arm.

Alternatively the attachment arm is formed of articulated portions which may be mutually articulated
20 during rotation to vary an effective length of the attachment arm.

A preferred inventive feature will be seen to reside in the adjustment means including carriage means for carrying the sun blocker component and transport means
25 for moving the carriage with respect to the spacecraft.

Conveniently the transport means includes guide means and the carriage means includes drive means to drive the carriage along the guide means.

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Preferably the transport means includes guide means
and motive means that are external to and connected to
the carriage means , the external motive means being
5 driven by

drive means to move the carriage means along the guide means.

Alternatively the transport means includes an
 5 annulus rotatable in a circular path defined by bearing means, the annulus being driveable by drive means to move the carriage along the path defined by the bearing means.

Conveniently the spacecraft has a solar cell array
 10 adapted for tracking movements of the sun relative to the spacecraft, wherein the adjustment of the location of the sun ray blocker device in relation to the thermal radiator surface is synchronised with the tracking movement of the solar cell array, when in normal
 15 operation.

Conveniently the sun ray blocker device is mounted on the solar cell array or on means carrying said solar cell array.

Advantageously the solar cell array is adapted for
 20 tracking the movement of the sun by rotation of the solar cell array about an axis of rotation of the solar cell array such that the sun blocker component also rotates about said axis of rotation of the solar cell array.

Conveniently the thermal radiator surface is
 25 orthogonal to the axis of rotation of the solar cell array so that the sun blocker component rotates about an axis normal to the thermal radiator surface.

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Conveniently adjustment means for attachment of the sun blocker component to a solar cell array assembly are such that a distance between the sun blocker component
5 and the solar cell array assembly may be varied during rotation of the sun blocker component.

Conveniently the sun ray blocker device is adapted for tracking the movement of the sun by rotation of the sun ray blocker device about an axis of rotation of the
10 sun blocker device which is orthogonal to the thermal radiator surface so that the sun blocker component rotates about an axis normal to said thermal radiator surface.

Conveniently means are provided for adjusting the
15 form and/or size of the sun blocker component.

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Conveniently the spacecraft includes control means for controlling the spacecraft so as to maintain an angle between a sun line and the thermal radiator surface below a predetermined angle by adjustment of the orbit and/or attitude of the spacecraft in use.

5 Preferably the predetermined angle is 60 degrees.

More preferably the predetermined angle is 45 degrees.

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Most preferably the predetermined angle is 23.5 degrees.

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Advantageously the control means is adapted to maintain the thermal radiator surface substantially
5 parallel to a plane of an orbit of the spacecraft.

Alternatively the control means is adapted to maintain the spacecraft in a sun synchronous orbit.

Alternatively, the control means is adapted to maintain the spacecraft in an equatorial or low-
10 inclination orbit.

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5 The present invention preferably provides a sun-
synchronous sun ray blocker device (not to be confused
with sun synchronous orbits referred to elsewhere herein)
for use in a spacecraft designed to orbit around a planet
with solar incidence at low angles to their thermal
radiator surfaces, i.e. with sun directions close to the
10 planes of the individual radiator surfaces. Preferred
embodiments of the present invention are spacecraft for
operating in an orbit plane oriented at a

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low angle (or within a range of low angles) to the sun direction, the said spacecraft having a thermal radiator surface that is oriented approximately parallel to the orbit plane and a solar array assembly that is rotated
5 about an axis approximately perpendicular to the orbit plane nominally at the orbital rate. Examples of appropriate orbits are: (a) low inclination orbits around the Earth (including nominally equatorial orbits), and
10 (b) sun synchronous orbits with low orbit-sun angles (which around Earth and Mars, for example, are nominally polar orbits). The term "spacecraft" as used herein includes satellites and other space bound vehicles.

Mounted on any spacecraft to which the present
15 invention is applied is at least one device for blocking sun rays and thereby preventing them from directly impinging on a radiator surface of the spacecraft.

In many embodiments of the present invention the
20 individual spacecraft will have at least one solar array assembly (comprising solar cell panels and rotary axial booms) which may be used as mounting support for the sun ray blocker device(s), so that the combination assembly of solar array assembly and sun blocker device(s) is
25 operationally controllably rotated together as an integral unit to track the Sun throughout the orbital revolutions of the spacecraft, said solar array assembly being mounted on the spacecraft so that operationally in orbit it can be rotated about an axis that is maintained
30 oriented approximately perpendicular to the orbit plane in a manner such that the solar-cell side of the solar cell panels is maintained sun facing and substantially

of weather monitoring and remote sensing of the planet and its atmosphere. Some of the benefits of these sun synchronous orbits are: low spacecraft altitudes, frequent over-flight of the planet within close proximity
5 of virtually all latitudes and longitudes, and near constant angle of solar illumination on the day side of the orbit.

Means of adjusting the attitude and orbit of
10 spacecraft are well known, for example, are described in "Principles of Communications Satellites" by Gary D Gordan and Walter L Morgan published by John Wiley & Sons 1993, pages 12-14, 55-58 and in "Spacecraft Attitudes, Termination and Control" by James R Wertz published by
15 Kluwer Academic Publishers 1978. Attitude and orbit control may for example be provided by the use of thrusters and/or momentum or reaction wheels.

Typically, the attitude (i.e. the orientation) of
20 these types of satellite is controlled so that as the satellite orbits the planet part of its payload equipment steadily faces approximately toward the center of the planet, while the solar arrays are maintained sun pointing. The attitude (orientation) control systems of
25 such spacecraft belong to various classifications that are well known within the space industry. For example, two of the more currently prominent types of attitude control system are commonly referred to as "three-axis-stabilized" control systems and "spin stabilized" control
30 systems. The present invention device functions independently of the type of attitude control system, and independently of the orientation of spacecraft equipment

other than the orientation of the thermal radiator surfaces that the device shields from solar energy. In these types of spacecraft, the performance of the present invention device is generally better the closer the
 5 shadowed thermal radiator surface is to being parallel to the orbit plane (which in these types of spacecraft is maintainable at a low angle to the sun line).

Hereinafter, the concept of a "model spacecraft" is defined and employed in order to avoid the distraction of
 10 multiple lengthy descriptions of diverse spacecraft to which the present invention device may be applied. The model spacecraft is used herein, somewhat like a tailor's dummy, in order to facilitate the illustration and explanation of features, functions, and examples of
 15 applications of the present invention device.

By definition the model spacecraft has a basic, deployed (i.e. unfolded), structural configuration that is typical of many current three axis stabilized
 20 satellites, and a corresponding operational mode that is typical of a 3-axis-stabilised geostationary Earth pointing spacecraft. Note that this definition was selected on the basis of current estimates of the most frequent future application of the present invention
 25 device. The definition of the model spacecraft could equally well have been based on typical characteristics of another relevant type of spacecraft, for example an Earth-pointing spacecraft in a sun synchronous orbit with a low orbit-Sun angle.

30

Referring to FIGURES 1 and 5, the basic structural configuration of the model spacecraft is based on a main body in the form of a hollow, right parallelepiped. For

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the stated purposes of using the concept of the "model spacecraft" herein, it is useful to consider the main body as comprising six principal, planar, structural panels. The external surfaces of one opposing pair of
5 the six panels that form the main body of the model spacecraft constitute the mounting sites for the thermal radiator surfaces that are shielded from direct solar heating by means of the present invention device. Mounted on one or each of these two radiator-bearing
10 panels, and extending perpendicularly outwards therefrom, is a solar array assembly, comprising a rotary solar array boom to which are attached solar cell panels.

That is not to say that application of the present
15 invention device is limited to spacecraft with a structural configuration and/or an operational mode resembling that(those) of the model spacecraft. For example, the present invention device is also applicable to: sun synchronous spacecraft in orbits with low orbit-
20 Sun angles; spin stabilized spacecraft; spacecraft with polyhedral and/or irregular structures; spacecraft that are not nadir pointing; spacecraft that are not geostationary; spacecraft with solar arrays that deploy and subsequently lie along axes that are not
25 perpendicular to the radiator-bearing panels; etc.

Much of the text herein that supports the accompanying claims is written with reference to the model spacecraft or to 3-axis-stabilised Earth-pointing
30 geostationary spacecraft. Regardless, the supporting text also applies to applications of the present invention device to other suitable types of spacecraft. For example, the principal relevant difference between

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many suitable sun synchronous spacecraft (for polar
orbits at Earth and

like the model spacecraft are referred to as the north and south panels.

To avoid unnecessary further repetition, in
5 illustrating and explaining the features and functions of the present invention device herein, reference shall be made to application of the present invention device to the (previously defined) model satellite, which is operated in a three-axis-stabilized, Earth-pointing,
10 geosynchronous mode.

Through each orbital revolution of a spacecraft like the model spacecraft, which in a preferred embodiment is around the Earth, the Sun sequentially directly
15 illuminates the east, zenith, west, and nadir main-body panels. While illuminated (or insolated) thus these main-body panels absorb incident solar energy and their temperatures increase, which significantly reduces their net radiative cooling capability. If not countered by
20 some means this can significantly limit the quantity of equipment (which dissipate heat into the spacecraft) that can be carried on board, and/or can result in undesirably elevated temperatures of associated spacecraft equipment. The north and south panels, however, generally face deep
25 space during the entire orbit and only directly receive solar illumination and solar energy at relatively low

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incidence angles on a seasonal basis. Because the direct input of solar energy into the north and south panels is relatively low to zero, these panels are the principal sites on spacecraft like the model spacecraft for the
5 locations of thermal-energy radiator surfaces. The north panel is directly heated by the Sun for a duration of about 6 months (from about March 21st to about September 21st) at an incidence angle, defined as the angle between the panel plane and the sun vector, which seasonally
10 increases from 0 degrees (when the sun vector is edge-on to the panel) to about 23.5 degrees followed by a decrease to 0 degrees again while the Sun is on the north side of the earth equator, i.e. during the northern spring and summer. The south panel is directly heated by
15 the Sun for the remainder of the year, i.e. during the southern spring and summer, in a similar fashion and concomitantly with the north panel. These relatively low solar incidence angles favor use of the north and south panels for locating the principal thermal radiator
20 surfaces of the spacecraft. At a maximum incidence angle of 23.5 degrees for the solar vector relative to the north and south panels the incident solar energy is approximately 40% of that for normal (perpendicular) incidence.

25

In the prior art numerous design practices have been employed to the surface treatment of the north and south panels in an effort to reduce the absorbed solar energy, thereby allowing more internal heat dissipation without
30 raising the operational temperature level of the equipment that is thermally coupled to the panels. One example, optical surface reflectors (OSRs), which have a

Therefore, by virtue of the present invention, the spacecraft could be operated at a higher efficiency, with higher reliability, and would thereby generate revenue at a faster rate, all of which improvements would increase
5 its value.

There is another important factor that affects the capability of a thermal radiator surface to reject heat to deep space: the "effective" radiation view factor
10 (ranging from 0 to 1) from that panel to deep space. The ideal radiation view factor enabling a panel to reject maximum heat into deep space is unity (1). A device or means situated between the radiator surface and deep space could block the radiator's view to deep space and
15 thus reduce the heat-radiating capability of the radiator.

The sun ray blocker device of this invention is mounted on the spacecraft, for example conveniently
20 attached to the solar array assembly/assemblies of the spacecraft and rotating therewith. Since the primary function of the sun ray blocker device used in this invention is to provide a significantly more benign thermal environment for the principal thermal radiator
25 surfaces (or panels), basically by shading them, the spacecraft should have at least one such surface. In the case of three-axis-stabilized Earth-pointing geostationary spacecraft, for example, there are two principal thermal radiator surfaces - the north and south
30 panels; and accordingly at least two separate sun ray blocker devices can be included, one to shade each of these panels. Thus, the sun ray blocker device in the

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present invention follows the movement of the Sun with respect to the thermal radiator panel(s) that it shades. In the case of a three-axis-stabilized Earth-pointing geostationary spacecraft, like the model spacecraft for
5 example, the sun ray blocker device casts its shadow onto its associated thermal radiator surface, which is on either a north or a south panel, seasonally - through the six month long northern spring and summer in the case of the north panel, and through the six month long southern
10 spring and summer in the case of the south panel. The (counter-productive) reduction in the radiation-view-factor of the thermal radiator surface caused by the presence of the associated present invention device is small; and the net effect of this reduction combined with
15 the (beneficial) shading of the panel is a great improvement in the radiative efficiency of the radiator surface.

In addition to the foregoing, some of the
20 considerations, advantages and parameters for the present invention device are as follows (others will become self-evident from the subsequent discussion of the FIGURES):

Variety in the operational form and size of the sun
25 ray blocker device is permissible. The sun blocker component follows the movement of the Sun with respect to the spacecraft, and it blocks the Sun's rays by casting a shadow onto its associated thermal radiator surface at appropriate times, and it produces close to the minimum
30 reduction in the effective radiation view factor to deep space of the thermal radiator that it shields, and it

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satisfies other system requirements of the spacecraft (for example clear field of view requirements), as appropriate.

5 The material and/or the construction of the sun blocker component of the sun ray blocker device is preferably highly thermally insulating between its sun and anti-sun sides in order to provide the greatest practical effective radiation view factor and radiative
10 efficiency of the radiator-surface shielded by the sun blocker component.

 In its fully deployed configuration the sun blocker component may be mounted through a wide range of
15 orientations relative to the radiator surface that it shields (for example, the angle 501 in FIGURE 12a below does not have to be 90 degrees i.e. a right angle. A requirement is that the sun blocker component casts shadow providing adequate coverage of the associated
20 thermal radiator surface(s) on the spacecraft.

 The ideal width of the sun blocker component is greater than either the width or the length of the radiator surface that it shields. However, the
25 dimensions of the sun blocker component may be limited by other constraints. For example, in the launch configuration the dimensions of the sun blocker component may be limited by launch-envelope constraints, i.e. the size of the volume allowed for the spacecraft by the
30 launch vehicle during launch. Therefore, it may be necessary to make the sun ray blocker component deployable to enable it to be folded or retracted for

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launch and deployed in orbit. This can be achieved by
hinged

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deployment, slide extension, pre-offset or any other
means to increase the width of the sun blocker

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component (see FIGURES 16a, b and c, and 17a, b and c discussed below).

5 The mechanisms for extending, deploying, and
supporting the sun blocker component may include various
techniques and devices that are well known in the current
state of the art of the design of mechanisms for
spacecraft. For example the techniques and devices
employed could include mechanisms constructed from well
10 known device types such as: hinges, flaps, slides, spring
motors, wax motors, detentes, cable/bolt cutters, split
nut releases, pin pullers, hook and pin releases, etc.
Alternatively or additionally, so-called "active" devices
such as electrical motors may be used at the discretion
15 of the spacecraft designer. For example, one or more
electrical motor (for example a stepper drive motor)
could be employed to produce the motions resulting in
extension (and possibly also retraction) of the sun
blocker component. Such active control could be utilized
20 to facilitate certain operations of the spacecraft, for
example station-keeping and attitude control operations
for which displacing the sun blocker device from the
exhaust plume fields of rocket thrusters would be
beneficial.

25

 The present invention device is applicable to
spacecraft other than those spacecraft, like the model
spacecraft for example, which operate in the low-
inclination or equatorial orbits that have been described
30 thus far herein. It is applicable to the broad class of
spacecraft for which the solar illumination (insolation)
is incident at low angles relative to the planes of the

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surface(s) of their thermal-radiator surface(s).

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A certain subset of spacecraft belonging to the set of spacecraft that are well known in the space industry as "sun synchronous" fulfil this requirement for low solar incidence angles on at least one thermal radiator surface; and the present invention is applicable to them. Within this subset of sun synchronous spacecraft is an even smaller but well known subset comprising those spacecraft that operate in orbits with low orbit-Sun angles and in which the thermal radiator surfaces are utilized while oriented close to parallel to the orbit plane. A sun ray blocker device according to this invention is applicable to those spacecraft, to provide them with a shaded, benign, and desirable thermal environment for their thermal-radiator surfaces basically by protecting them against direct solar heating. Note, however, that when the angle of incidence of direct sunlight on the thermal radiator surface is zero (i.e. for grazing incidence) or less the sun ray blocker device is unnecessary.

Heretofore the structural configuration and orientation of spacecraft to which the current invention device is applicable have mainly been described with reference to three-axis-stabilized Earth-pointing spacecraft for operating in low inclination or equatorial orbits, like the model spacecraft for example. The fundamental difference between those preceding descriptions and the structural configurations and orientations of the sun synchronous spacecraft to which the current invention device is applicable stems from the orientation of the orbit with respect to the axis of rotation of the planet. Within the space industry, sun

synchronous orbits are widely referred to as being
 "polar", since the orbit plane of a sun synchronous
 orbit, around Earth and Mars at least, lies within
 several degrees of the axis of rotation of the planet;
 5 and therefore nominally includes the planetary poles.
 Therefore, for the aforementioned particular subset of
 sun synchronous spacecraft to which the current invention
 device is applicable, the panels and the radiator
 surfaces on them that are thermally protected by the
 10 current invention device are generally not, strictly
 speaking, "north" and "south" panels. However, herein
 the terms "north" and "south" are occasionally used for
 convenience to indicate the panels that are thermally
 protected by the sun blocker device on spacecraft in sun
 15 synchronous orbits as well as on spacecraft like the
 model spacecraft, for example, in (nominally) equatorial
 orbits. The rationale is that in the particular,
 suitable, well known, and currently populous,
 aforementioned, subset of sun synchronous spacecraft the
 20 planes of thermal radiator panels shielded by the present
 invention device are also approximately perpendicular to
 the axis of the orbit (as for spacecraft like the model
 spacecraft in its orbital configuration and orientation).
 For both these types of spacecraft we could instead
 25 meaningfully refer to the protected panels and radiator
 surfaces as "pitch-axis" or "orbit normal" panels and
 surfaces, because the pitch axis of the spacecraft (which
 is parallel to the orbit normal) is
 nominally/approximately perpendicular to them and thereby
 30 defines their orientation.

Depending upon the requirements of the propulsion subsystem and/or the attitude control subsystem of the spacecraft, the spacecraft designer may elect to provide only one sun ray blocker device, i.e. on only one of the two sides of the spacecraft that face approximately along the pitch axis (e.g. on the north or the south panel for the model spacecraft). In any particular application there may be a preference for one side of the spacecraft over the opposite side because of other system requirements. For example, in a potential embodiment of the present invention device on a particular current design of geostationary spacecraft, the south side is preferred because of field of view requirements for attitude-control thrusters on the north side.

15

Again, if the spacecraft designer elects to do so, solar cells can be mounted onto the external surfaces of the sun blocker component to provide additional power to the spacecraft.

20

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention should be more fully understood when the specification herein is taken in conjunction with the drawings appended hereto showing exemplary embodiments of the invention wherein:

25

FIGURE 1 is a simplified perspective view of a prior art three axis stabilized Earth-pointing geosynchronous spacecraft;

30

FIGURE 2 shows an east-panel based view of the prior art spacecraft illustrated in FIGURE 1 orbiting in a low inclination or an equatorial orbit;

5 FIGURE 3a shows a north-panel based, top view of the prior art spacecraft illustrated in FIGURE 1 orbiting about the Earth at different times of the day, and FIGURE 3b illustrates orbit-plane based views of that spacecraft at its noon, 6 a.m., and midnight positions and also
10 establishes sun angles for different seasons of the year;

FIGURES 4a and 4b show the variation in the solar incidence angle on the north and south panels, respectively, of the prior art spacecraft illustrated in
15 FIGURE 1 orbiting Earth, through one calendar year;

FIGURE 5 illustrates a perspective view of a spacecraft configuration according to the present invention, based on the prior art spacecraft illustrated
20 in FIGURE 1;

FIGURES 6a, 6b and 6c illustrate top views of a present invention arrangement as applied to the prior art spacecraft illustrated in FIGURE 1. The views shown are
25 simultaneously parallel to both the orbit-plane and the plane of the solar cell panels and the sun blocker components of the sun ray blocker device. Hereinafter this view direction is also referred to as "top view". FIGURES 6a, 6b and 6c show that as the spacecraft
30 revolves around the orbit the earth panel always faces the Earth, and the cell-side of the solar array panels together with the

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front (sunward) sides of the sun blocker components of the sun ray blocker devices always face the Sun;

FIGURES 7, 8 and 9 illustrate top views of present invention devices utilizing different attachment
5 arrangements;

FIGURES 10a, 10b and 10c illustrate portions of top views of one of the solar array assemblies of a prior art spacecraft before, during, and after its deployment;
10

FIGURES 11a, 11b, 11c, 12a, and 12b show, in top view, aspects of the deployment and the function of present invention devices as applied to the prior art spacecraft shown in FIGURES 10a, 10b, and 10c;
15

FIGURES 13 and 14a show partial top views of two alternative present invention devices; and FIGURE 14b shows a partial back (anti-sun) side view of the arrangement shown in FIGURE 14a;
20

FIGURES 15a and 15b show partial top views of an alternative present invention device in its fully deployed and partially deployed configurations, respectively;
25

FIGURES 16a, b, and c show a view of an alternative present-invention device from the front (sunward) direction with the sun blocker device fully deployed, and two views from a direction orthogonal to both the front
30 view and the (previously defined) top view directions

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with the sun blocker device folded and deployed,
respectively;

5 FIGURES 17a, b, and c show a different alternative
present-invention device in the same views and deployed
states as those shown in FIGURES 16a, b, and c;

10 FIGURE 18 shows a further embodiment of the
invention;

FIGURE 19 shows another embodiment of the invention;

FIGURE 20 shows another embodiment of the invention;

15 FIGURES 21 to 24 and 26 show another embodiment of
the invention;

20 FIGURE 25 shows details of the embodiments of
FIGURES 21 and 24 and 26;

FIGURES 27 to 30 show another embodiment of the
invention; and

25 FIGURES 31 and 32 illustrate alternative shapes for
sun blocker components used in the present invention.

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Referring now to FIGURE 1, there is shown an oblique view of a fully deployed (i.e. fully unfolded from its launch configuration) spacecraft (or satellite) 1, like the previously described model spacecraft for example,
5 which is represented by a main body 10 which contains six external panels: 11, 12, 13, 14, 15 and 16, a group of

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antenna reflectors 20, 21, 22 and 23, and two solar array assemblies, consisting of two solar arrays (one or more solar cell panel) 100 and 101 and their supports 100a and 101a by which they are connected to the main body 10, which are extended northward and southward from the main body out of the north and south panels 11 and 12, respectively. The number of antenna reflectors is driven by the need of the telecommunications application and is a matter of design. In this example, four reflectors are shown and are represented by two deployable large reflectors 20 and 21 mounted on east and west panels 15 and 16, respectively. Two non-deployable reflectors 22 and 23 are mounted on nadir panel 14. While orbiting in a low inclination orbit about Earth, the spacecraft is controlled in such a way that the earth or nadir panel 14 is pointing in the general direction of the center of the Earth, thus allowing the antenna reflectors to perform telecommunications functions with Earth. Opposite to the earth panel 14 is the zenith panel 13.

20

The solar arrays 100 and 101 may contain multiple panel elements (typically two to eight or more on each side - a four panel-element example is shown in FIGURE 1) or may contain as few as one panel element. However, usually solar arrays comprising multiple solar cell panels are utilized, in order to provide sufficient electrical power for the spacecraft's use. The size and number of the solar cell panels is driven by mission power requirements, and is constrained by, among other factors, the capability of the attitude control subsystem to maintain pointing stability and also by the capability of the thermal control subsystem to manage the heat

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for a portion of the calendar year. These periods are nominally 21 March through 21 September for the north panel, and 21 September through 21 March for the south panel. Therefore, the sun ray blocker devices of the
5 current invention perform their shading functions for their respective radiator panels for those periods only.

FIGURE 5 illustrates one preferred embodiment of the current invention, which eliminates or greatly reduces
10 the seasonal solar input on the north and south panels 11 and 12, thus providing more efficient thermal radiators for the spacecraft.

In this present invention embodiment, the sun ray
15 blocker devices (581, 582) comprise two sun blocker components 111 and 112 and mounting, supporting, and deployment mechanisms by means of which the blocker components are integrated with and deployed with the structures and mechanisms that support and cause the
20 solar array to rotate. The radiators on the north and south panels 11 and 12 have dedicated sun ray blocker devices 581 and 582 attached to the north and south array assemblies 100 and 101, respectively, as shown in FIGURE 5. After the thus modified spacecraft 1 has been
25 launched into the operational orbit and its appendages have been fully deployed, the sun blocker components 111 and 112 will achieve their final positions in front of the cell side of the solar arrays with their surfaces more or less parallel to the plane of the solar arrays.
30 The south blocker device 582 is positioned such that during the time between the northern autumnal and northern spring equinoxes, when otherwise there would exist a potential for solar heating

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of the south panel 12, the south blocker device 582 will cast a shadow over the south panel 12 thereby eliminating the potential for such solar heating. The north blocker device 581 performs a similar function relative to the
5 north panel 11 during the time between the northern spring and northern autumnal equinoxes. When the solar array assemblies 100 and 101 are maintained directly sun pointed, by virtue of their being rotated, the sun blocker devices will likewise be maintained directly sun
10 pointed and thereby interposed between the Sun and the north and south panels that they shade.

The materials used for the sun blocker components 111 and 112 are selected to minimize the heat transferred
15 from their sun facing surfaces 111a and 112a to their anti-sunward surfaces 111b and 112b. This may be achieved by including insulating material(s) and constructions in the composition of the sun blocker components. For example, sun blocker components may include known
20 thermally insulating materials and assemblies of materials, such as multi-layer insulation (MLI) blankets which utilize layered films of metallized Mylar separated by fabric netting. These materials and constructions are well known in the space industry and have typical heat
25 resistance values of 0.007 to 0.01 Watt/deg.C/sq.in, i.e. 0.0011 to 0.0016 Watt/deg.C/sq.cm. The sun blocker components of the present invention device will generally experience a sizeable temperature difference, for example possibly greater than 100 degree C, between surface 111a
30 and surface 111b and between surface 112a and surface 112b when the satellite is in its normal orientation in the mission orbit, except when the spacecraft is passing through the Earth's shadow.

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To obtain the maximum sun blocking effect, the sun blocker components of the sun ray blocker devices 111 and 112 are configured (sized, oriented, and positioned) in such a way that at the summer and winter solstices, when the Sun is about 23.5 degree from the orbit plane, the sun blocker devices will cast shadows that entirely cover the radiator surfaces on their respective thermal radiator surfaces on the spacecraft panels 11 and 12. Accordingly, if the radiator surfaces are rectangular the shadows must be at least as wide as the diagonals of the rectangles.

FIGURES 6a, 6b and 6c show top partial views of a present invention arrangement as the spacecraft orbits Earth and the main body 10 is rotated at the orbital rate so that the earth panel 14 always faces Earth, and the sun blocker components 111 and 112 of the sun blocker devices 681 and 682, respectively, always face the Sun (which is at the left in the FIGURES). These FIGURES are drawn in the inertial frame of reference of the solar array assemblies 100 and 101. Thus, if one were to stand on either of the solar array assemblies 101 and 102 one would see main body 10 rotate one revolution per orbital revolution around the Earth.

FIGURE 7 is a top partial section view showing more details of a present invention spacecraft. In this context the phrase "top view" denotes a view parallel to the planes of the sun blocker components 111 and 112 and also parallel to the orbit plane. Note that in Figure 7 through Figure 15b various examples of embodiments of the present invention are depicted together with generic

partial views of a spacecraft main body and a solar array assembly (labelled 400 and 408, respectively, later in FIGURES 10 and FIGURES 11). Additionally, FIGURES 8 and 9 show alternative embodiment arrangements in top partial section views.

In FIGURE 7, the spacecraft has main body 10, north panel 11, and solar cell panel support 223 with attached solar cell panel 225. In this case, there is a connecting solar array boom-and-yoke 219 and hinges at hinge points 221 and 227. Together this solar cell panel support 223, a solar cell panel 225, a solar array boom-and-yoke 219, and the hinges at hinge points 221 and 227 comprise part of a solar array assembly. The solar array boom-and-yoke 219 fold forwardly against north panel 11 and the solar cell panel support 223 together with the solar cell panel 225 folds down at hinge point 227 in an accordion-like fashion for launching. During launch, ascent, and orbit achievement the solar array assembly is in its folded-closed configuration. After achievement of the mission orbit it is electro-mechanically and/or mechanically deployed (unfolded) to allow the solar cells to be maintained directly sun-pointed. Attached to solar cell panel support 223 is a two-section connecting arm having a short inner portion 209 and an outer portion 207 connected by hinge(s) at hinge point 215. The anti-sunward side 111b of sun blocker component 111 is connected to outer arm portion 207 by hinge(s) at hinge point 203. Optional solar cells 201 are functionally positioned on the sunward surface 111a of the sun blocker component 111. Hinge points 203 and 215 provide for folding of the solar blocker component 111 and its hinged arm 207 against the

solar cell panel 225 in a compact and stiff configuration suitable for launch and subsequent deployment. The electromechanical and/or mechanical designs and methods for deploying (opening) and closing solar array
5 assemblies are commonly used in contemporary spacecraft. The same or similar mechanisms are used to deploy the sun ray blocker devices of the present invention. These mechanisms and methods for deployment and closing are well within the skills of the artisan.

10

In FIGURE 7, there is an imaginary plane 250 extending off the surface of north panel 11. In its deployed configuration the sun blocker component 111 may touch or extend through this imaginary surface, and
15 consequently may provide additional shading for the earth, west, zenith and east panels as they rotate with respect to the Sun.

FIGURE 8 shows an alternative embodiment where sun
20 ray blocker component 271 does not intersect imaginary plane 250. Further, it has a single connecting arm 205 with hinge points 203 and 217 at opposite ends to form an assembly and is connected directly to the substrate of solar cell panel 225. It may be folded and stowed for
25 launch and deployed or unfolded in orbit in a similar way to the sun ray blocker device in FIGURE 7. In FIGURES 7 and 8, the sun ray blocker devices cast their shadows over the major part of the outer surface of north panel 11 and, in these embodiments, completely shadow that
30 surface during the times when otherwise they would be exposed to the Sun. Further, the solar cells 201 may be

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included to produce additional solar power for the spacecraft.

In FIGURE 9, identical parts to FIGURES 7 and 8 are
5 identically numbered. Sun ray blocker component 301 is
connected directly to solar cell panel support 223 by
hinge(s) at hinge point 309 so as to fold over up-close
against solar cell panel 225 in the launch configuration.
In this embodiment, sun ray blocker component 301 is not
10 parallel to the solar array, yet still effectively shades
north panel 11.

FIGURES 10a, 10b and 10c depict a typical prior art
sequence of deployment of a solar array assembly, which
15 is part of the transformation of the spacecraft from its
launch configuration to its configuration for normal
operations in orbit. For simplification in this
document, only one (the north) solar array assembly is
shown in the FIGURES. These particular FIGURES show a
20 satellite with a main body 400, and a solar array
assembly 408 comprising four solar cell panels, with
solar cell surfaces 400a, mounted on solar cell panel
supports 408 which are interconnected by hinges at three
hinge points 403, 404, and 405 and connected to the main
25 body 400 by a single boom 419 and hinge(s) at hinge
points 401 and 402. FIGURE 10a depicts the solar array
assembly folded and stowed for launch. FIGURE 10b
depicts it in the process of being deployed (unfolded).
Figure 10c depicts its fully deployed state. If a
30 multiple-arm boom design is desired by the spacecraft
designer, various embodiments can be designed to satisfy

performance requirements using greater numbers of arms and hinge points.

FIGURES 11a, 11b and 11c illustrate the deployment
5 sequence of one possible design embodying the present
invention. Components in FIGURES 11a, 11b, and 11c that
are identical to components in FIGURES 10a, 10b, and 10c
are numbered identically to their identical parts. In
addition to the prior art solar array assembly that was
10 previously depicted in FIGURES 10a, 10b and 10c, FIGURES
11a, 11b, and 11c also depict the present invention sun
blocker component 411 connected to the solar array boom
419 by an arm 430 and hinges at hinge points 406 and 407.
Alternatively, by design the sun blocker component 411
15 could be hingedly attached via the arm 430 to a
convenient different location on the solar array
assembly. FIGURE 11a depicts the solar array assembly
and the sun ray blocker device folded and stowed for
launch, FIGURE 11b shows them partially deployed
20 (unfolded). FIGURE 11c depicts their fully deployed
state. FIGURES 12a and 12b show sun blocker components
which are not parallel to the plane containing the solar
cell panels yet which still provide proper shading of the
north or south panel. Components in FIGURES 12a and 12b
25 and subsequent figures that are identical to components
that appear in previous figures are numbered identically
with their corresponding or very similar components or
are left un-numbered to avoid unnecessary repetition.
Alternatively, by design the sun blocker component 111
30 could be hingedly attached via the arm 430 to a
convenient different location on the solar array
assembly.

FIGURE 13 depicts yet another alternative embodiment of the present invention. The sun blocker component 511 is connected to the solar array boom 219 by hinge(s) at hinge point 507 for its stowing folded and subsequent
5 deployment.

FIGURES 14a and b show an arrangement similar to that in FIGURE 13, with identical parts identically numbered, however, more hinges at hinge points 606 and
10 607 are used with sun blocker component 611 as required by design for folding the sun blocker components prior to deployment.

FIGURE 14b represents a partial view of the anti-
15 sun side of the spacecraft looking toward the Sun (i.e. a side view relative to the top view shown in Figure 14a).

FIGURES 15a and 15b show one embodiment in which sun blocker component 811 utilizes separate active motors 306 and 307 which are used to actively deploy and/or retract
20 the sun ray blocker device. This arrangement allows satellite operators to use deployment motors that are separate from the solar panel deployment motors so as to permit them to retract the sun blocker devices to prevent
25 their interference, if any, in satellite operations such as in the use of propulsion systems during spacecraft performance of station keeping or attitude control maneuvers.

30 In some spacecraft designs the required size (dimensions and/or area) of a sun blocker device in its fully deployed configuration may exceed the constraints of its "launch envelope" i.e. the constraints of the

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maximum-allowable space allocated to the sun ray blocker device in the launch configuration of the spacecraft when the solar array and the sun ray blocker device are in their launch configuration. Therefore, for compatibility with the constraints of the size of the corresponding launch envelope it may be necessary for the sun blocker component of the sun ray blocker device to comprise several (i.e. more than one) pieces, instead of being one single integral piece, which are folded together in the launch configuration and are subsequently deployed (unfolded) in orbit to form effectively one continuous sun blocker component. FIGURES 16a, 16b and 16c, and FIGURES 17a, 17b and 17c, respectively depict two examples from the many possible designs for sun blocker components which fold and deploy. Parts a, b, and c of the FIGURES 16 and 17 show each of the two designs in a view from the front (Sun) direction with the sun blocker device fully deployed, and two views from a direction orthogonal to both the front view and the top view directions with the sun blocker device folded and deployed, respectively. (As defined earlier herein the phrase "top view" denotes a view that is simultaneously parallel to the plane of the sun blocker components 921 or 951 and the orbit plane.) This allows the sun ray blocker device to increase its dimensions using hinge(s) and/or strut(s) and/or flap(s) etc. at hinge points 925 and 927 or a slide-out design. Referring collectively to all FIGURES 16, sun blocker component 921 has a center section 923 with hinge(s) and/or strut(s) and/or flap(s) etc. at hinge points 925 and 927 and outer, swing up sections 929 and 931 which may be designed to deploy (swing up) automatically. In all FIGURES 17, sun blocker component 951 has main section 953

with slide-out extensions 955 and 957 that may be designed to deploy (slide out) automatically. (Automatic hinging and automatic sliding or telescoping is well within the purview of the artisan in the spacecraft industry and need not be further elaborated upon herein.)

The embodiments of the present invention device illustrated in FIGURES 18 through FIGURE 30 are as generally applicable as the other embodiments described herein. However, they also function efficiently in cases where a sun blocker device cannot be attached to an axle located near the center (1811, 2123, 2722) of an associated thermal radiator surface (1804, 2121, 2721).

One such case is that in which the axis of rotation (1803, 2131, 2701) of a solar array assembly extends outward from the associated thermal radiator surface (1804, 2121, 2721) at a location that is significantly offset from the center (1811, 2123, 2722) of the thermal radiator surface. In that case, designs with an attachment arm of fixed length between the sun blocker component and the solar array axis could be unsuitable, because the motion of the sun blocker component about the center of the thermal radiator surface would be eccentric.

Another such case is that in which there are stay-out zones inboard of the periphery of the associated thermal radiator surface - through which objects such as a supporting boom (for example for a sun blocker component) are not allowed to pass. This could be the case, for example, when certain attitude- or orbit-control

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thrusters (1810) are also located on the main-body panel of the spacecraft upon which the thermal radiator surface (1804) is located.

5 The arrangements illustrated in FIGURES 18 through
FIGURE 30 may be employed to overcome these constraints,
whilst still maintaining a sun blocker component at a
substantially uniform distance from the center of the
associated thermal radiator surface and achieving compact
10 static and swept volumes of a sun blocker device.
Selection between the embodiments shown in FIGURES 18-30
for any particular application may involve trade-offs
between many additional performance-requirements of the
spacecraft-system, including for example: mass, strength,
15 stiffness, flatness, circularity, simplicity, and
reliability.

Figure 18 shows an embodiment of a sun blocker
device in which the sun blocker component 1800 is mounted
20 on a carriage 1801 with wheel-sets or bearing-sets 1808
and 1830 by means of an attachment arm 1805 in which the
carriage may be driven around a closed guide 1802 in at
least one of the directions of the arrows 1832, the
carriage 1801 being attached to the guide 1802 by rolling
25 or sliding means that also react against and thereby
limit rotations of the carriage 1801 (and thereby the sun
blocker component) about axes passing through the points
of contact of the carriage and the guide. In one of many
potential embodiments, for example, this may be achieved
30 using wheel or bearing sets 1808, 1830 that are
adequately spaced both along-track and cross-track on
both sides of the guide 1902, and which are also cambered
at an adequate angle to the plane of the baseplate.

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Attached to the carriage is at least one generally-radial boom or strut 1805, an outer end of which is attached to

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the sun blocker component at hinge point 1812 and an
inner

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end of which is attached to the carriage 1801 at hinge-point 1813, and the carriage is rollingly or slidably mounted on the guide 1802 by the wheels or bearings 1808 and 1830. At least one of these wheels or bearings 1830 is provided with a motor to rotate the wheel in at least one of the directions of the arrows 1831 and thereby drive the carriage along the guide 1802, for example by friction, or by the engagement of a toothed wheel or a worm-drive in a rack. Electrical power may be supplied to the motor, via brushes for example. The attachment arm 1805 and the sun blocker component 1800 can be folded at the hinge points 1812 and 1813 to achieve a stowed configuration of the sun blocker device for launch, during which the folded device may be temporarily caged securely for proper management of launch-induced dynamic environments and loads. The sun blocker device may be further folded for launch as illustrated in FIGURES 16 and 17. Following launch the attachment arm 1805 and the sun blocker component 1800 can be deployed for subsequent operation in orbit, including sun-tracking travel around guide 1802. It will be appreciated that the guide 1802 need not be circular as shown in FIGURE 18, but in the case of a significantly rectangular thermal radiator surface, for example, the guide could be elliptical and in either case may be diverted to avoid obstacles mounted on the spacecraft.

Alternatively, as illustrated in FIGURE 19 the attachment arm 1905 could be mounted on a solid rotatable wheel instead of on a carriage and guide, for example by an intermediate structure 1901, shown comprising elements 1906 and 1907. In the embodiment illustrated in FIGURE

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19 the wheel is a ring or annulus 1902 floating in
circumferentially located bearing-sets 1903 and

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controlled and driven by a motor 1930 mounted on the baseplate under 1804. The outer end of attachment arm 1905 is attached to the sun blocker component at hinge point 1812, and the inner end to the intermediate
5 structure 1901 at hinge-point 1913. Arrows 1931 and 1932 indicate rotation of the motor 1930 and resulting rotation of the sun blocker component, respectively.

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In a similar alternative embodiment, illustrated in FIGURE 20, a carriage 2001, similar to that provided in the embodiment illustrated in FIGURE 18, is provided; but in this embodiment the carriage 2001 is driven around a closed guide 2002 in at least one of the directions of the arrows 2032 not by a motorized wheel, but by external motive means such as an endless belt 2003, chain, or cable attached to the carriage 2001, the belt for example being driven by a motor 2030 that is mounted to the baseplate under 1804 and which engages the belt 2003, chain, or cord, and rotates in at least one of the directions of the arrows 2031. A tensioning device 2040 is also provided to engage the belt 2003 and tension the belt while not impeding the passage of the carriage around the guide 2002, for example by exerting a force on the belt in the direction of arrow 2042. Again, as in the embodiment illustrated in FIGURE 18 the guide 2002 need not be circular.

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5 FIGURES 21 through 30 illustrate embodiments in
which a sun blocker component is mounted on the
spacecraft via an attachment arm from an axis 2131, 2701
that is offset from the center 2123, 2722 of an
associated thermal radiator surface. The axis 2131, 2701
10 could be concentric with or identical to the axis of
rotation of a solar array assembly.

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FIGURES 21 through 26 illustrate an alternative embodiment in which a sun blocker component 2100 is
5 attached to an axle at axis 2131. The axle may be concentric with or identical to an axle of a solar array assembly. The sun blocker component is attached to the axle by an articulated attachment arm 2130 that includes three articulated portions 2132, 2134, 2137.

The inner end of the inner-portion 2132 is fixed radially to the axle at axis 2131. The middle-portion 2134 is pivoted at its inner end to inner-portion 2132 at pivot-point 2133, and the outer end of middle-portion
5 2134 is pivoted to the inner end of outer-portion 2137 at pivot point 2135. At its outer end the outer-portion is attached to the sun blocker component at hinge point 2138 and near its inner end the outer-portion is hinged at hinge point 2136 to allow folding and stowing for launch
10 followed by deployment in orbit.

As depicted in FIGURE 21 through FIGURE 26 the inner-portion 2132 and the outer portion 2137 of the attachment arm 2130 turn anti-clockwise at the same rate,
15 the outer-portion 2137 carrying the sun blocker component with it, whereas the middle portion 2134 rotates clockwise at the same rate.

The length of the inner-portion 2132 is
20 approximately equal to the offset of the axis of rotation 2131 from the center 2123 of the thermal radiator surface. In principle the length of the middle-portion 2134 may be longer or shorter than the length of the inner portion 2132. However, in the case that the axis
25 of rotation 2131 is occupied by an obstruction such as the axle of a solar array assembly then the middle-portion 2134 must be shorter than the inner-portion 2132 for clearance of the solar array axle at axis 2131, as can be seen in FIGURE 23 in which the attachment arm 2130
30 is approaching its closest to the axle at axis 2131.

By articulating the articulated portions through rotation of the arm 2130 about the axis of rotation 2131 the sun blocker component can be maintained at a substantially constant distance from the center of the associated thermal radiator surface 2121, to describe a substantially circular path 2140 around the spacecraft. It will be evident that in the case of a thermal radiator surface that is significantly far from being radially symmetric the length of the articulated portions of arm 2130 could be adapted to achieve a wide range of desired paths around the thermal radiator surface.

As shown in FIGURE 21, the articulated portions 2132, 2134, 2137 are arranged to the full reach of attachment arm 2130 in a straight line when the sun blocker component is passing a side of the thermal radiator surface furthest from the axis of rotation 2131. As shown in FIGURES 22 and 23 the attachment arm 2130 has an effective length equal to the sum of the lengths of an outer 2137 and an inner 2132 articulated portion when the sun blocker component 2100 is at an intermediate distance from the axis of rotation 2131. As shown in FIGURE 23, the effective length of the attachment arm 2130 is at its minimum when the sun blocker component is at its closest to the axis of rotation 2131, at which point its length is equal to the sum of the lengths of the inner 2132 and outer 2137 portions less twice the length of the middle-portion.

The inner articulated portion 2132 of the attachment arm 2130 rotates about axis 2131. The means of attachment of the inner articulated portion 2132 may be

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as the inner articulated portion 2132 whereas the middle articulated portion 2134 counter-rotates.

In a further embodiment illustrated in FIGURES 27
5 through 30, a sun blocker component 2700 is attached to
an axle 2701 of a solar cell array by means of a scissors
attachment arm 2730. The scissors arm comprises a first
articulated arm 2704, 2708 and a second articulated arm
2705, 2709, comprising inner articulated portions 2704,
10 2705 and outer articulated portions 2708, 2709
respectively. The inner articulated portions are
connected by hinges at hinge points 2702, 2703 to the
solar array boom 2701 respectively and the outer ends of
the outer articulated portions 2708, 2709 are connected
15 by hinges 2710, 2711 to the sun blocker component 2700
such that when the articulated arms are extended to the
full length they are still not parallel to avoid their
locking up. A lanyard 2712 is located in between the
articulated arms 2704, 2708 and 2705, 2709 and extends
20 between the sun blocker component 2700 and the solar
array axle 2701. The inner articulated portions 2704,
2705 and the outer articulated portions 2708, 2709 are
sprung at hinge points 2706 and 2707 so as to
automatically extend the articulated arms 2704, 2708 and
25 2705, 2709 to their full extent as limited by the lanyard
control. The articulated arms 2704, 2708 and 2705, 2709
thereby form a parallelogram, the shape of which may be
controlled by retracting or deploying the lanyard 2712.
Alternatively the shape of the parallelogram could be
30 controlled by motorized hinges, or alternatively by a
retractable and deployable lanyard between hinge points
2706 and 2707 with sprung hinges 2702, 2703, 2710 and
2711 instead of

at 2706 and 2707. In the embodiment of the invention illustrated in FIGURES 21 through 24, the distance of the sun blocker component 2700 from the solar array boom 2701 can be varied as the sun blocker component 2700 rotates
 5 about the solar array boom 2701 to maintain the sun blocker component at a constant distance from the spacecraft as illustrated by the path 2712.

The embodiments described in FIGURES 18 through 20
 10 have the advantage that the attachment arm does not obscure thrusters 1810 present on the face of the spacecraft, that the sun blocker component shades.

A sun blocker component 3100, 3200 is not
 15 necessarily rectangular in shape. As shown in FIGURE 31, the sun blocker component 3100 has trapezoidal first- and second- extensions 3101, 3102 hingedly attached to a main body 3103 of a sun blocker component 3100. The first extension 3101 is extended by unfolding the extension
 20 through rotation in the direction of the arrows 3104 and the second extension is extended by unfolding the extension through rotation in the direction of the arrows 3105 from a position flat against the main body 3103.

25 As shown in FIGURE 32 a rectangular main body 3202 of the sun blocker component 3200 may have substantially triangular extensions 3201, 3202 which may be extended and retracted from the main body by sliding translation of the extension 3201 in the direction of double-handed
 30 arrow 3204 and unfolding the extension 3202 in the direction of arrows 3205.

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FIGURES 5 to 9, 11 to 24, and 26 to 32 illustrate sun blocker components each of which includes a region of an anti-sun-facing surface adapted to lie, in an operational configuration, substantially in a plane.

- 5 FIGURES 5 to 8, 11, 12b, 15, 18 to 24, and 26 to 32 illustrate sun blocker components each of which includes a region of an anti-sun-facing surface adapted to face, in an operational configuration, at an angle away from an associated thermal radiator surface.

10

The descriptions of designs for the structural support and the deployment of sun ray blocker devices written herein are examples from thousands of possible structural support and deployment designs which can be
5 used for this purpose and are within the scope of the present invention.

This paragraph describes an example to demonstrate the geometrical approach to calculating the dimensions of
10 a sun blocker component for providing total shadow coverage to a quasi-rectangular shaped radiator surface. The example used is that of a radiator surface on a north or south panel of a geostationary spacecraft, like the previously defined "model" spacecraft for example, at the
15 summer or winter solstice, when the incidence angle of the Sun's rays (measured from the plane of the benefited thermal radiator surface) is at a maximum, using a quasi-rectangular (for this simple illustration at least) shaped sun blocker component whose plane is perpendicular
20 to the plane of the associated thermal radiator surface (referring to FIGURE 12a, angle 501 is then 90 degree). For this example, take the north or south radiator-surface of the spacecraft to be rectangular, of length and width A and B, respectively. Then, the length and
25 width dimensions, L and W, respectively, of the sun-exposed surface of the fully-deployed sun blocker component (which is shown in FIGURES 16a and 17a) should be as follows: L is greater than or equal to $\sqrt{A^2+B^2}$, and W is greater than or equal to $0.435 \times \sqrt{A^2+B^2}$ based on the
30 corresponding orbit-sun angle of 23.5 degree. However, if only a portion of the surface area on the north or south panel needs to be shadowed, i.e. high heat-dissipating

equipments were to be mounted in certain localized areas
 of the north or south panel, the sun ray blocker device
 can be tailored to shade only those areas and may
 accordingly be smaller. In addition, if a sun blocker
 5 component whose plane is not perpendicular to the plane
 of the associated thermal radiator surface were to be
 selected by the spacecraft designer, the minimum value of
 the width, W , may be greater or less than $0.435x \sqrt{A^2+B^2}$
 depending on the size of angle 501 in FIGURE 12a. If
 10 angle 501 is greater than 90 degree, W may be greater
 than $0.435x \sqrt{A^2+B^2}$; if it is less than 90 degree, W may
 be less than $0.435x \sqrt{A^2+B^2}$. If additional shading to
 the other four panels, earth, zenith, east and west
 panels, is desired, the width (W) of the sun blocker
 15 component can be increased to extend past the imaginary
 plane 250 toward the center of the satellite as shown in
 FIGURE 7.

Thus, by the foregoing descriptions contained herein
 20 it can be seen that by virtue of the present invention
 losses in the efficiency of the cooling of the thermal
 radiator panels of a spacecraft caused by solar heating
 can be eliminated or minimized via various sun blocking
 arrangements.

25

Obviously, numerous modifications to and variations
 on the present invention are possible in light of the
 above teachings. For example, as a practical matter, a
 designer might counterweight or counterbalance the
 30 rotating axles or arms to overcome the weight imbalance
 caused by sun ray blocker devices of the present
 invention without exceeding the scope of the present

invention. It is therefore understood that within the scope of the appended claims, the invention may be practised otherwise than as specifically described herein.

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CLAIMS

1. A spacecraft for orbiting a sunlit celestial body (300), the spacecraft including a thermal radiator surface (11,12,1804, 2121, 2721) for radiating heat from the spacecraft into space, and a sun ray blocker device (581, 582, 681, 682) mounted on said spacecraft for shielding said thermal radiator surface (11,12,1804, 2121, 2721) from rays of sunlight, characterised in that said sun ray blocker device (581, 582, 681, 682) includes at least one sun blocker component (111, 112, 271, 301, 411,511, 611, 811,921, 951, 1800, 2100, 2700, 3100, 3200), said sun blocker component being locatable, in an operational configuration, on a sun line from said thermal radiator surface (11,12,1804, 2121, 2721) and being of suitable shape, size, and orientation for placing in shadow up to the whole of said thermal radiator surface (11,12,1804, 2121, 2721) from sunlight, said sun blocker component having a surface (111a, 112a) intended to face the Sun in use and an opposed surface (111b, 112b) intended to face away from the Sun in use, said sun blocker component (111, 112, 271, 301, 411,511, 611, 811,921, 951, 1800, 2100, 2700, 3100, 3200) being adapted for achieving a high radiation view factor from the thermal radiator surface (11,12,1804, 2121, 2721) to deep space by means including thermal insulation material located between the sun-facing surface (111a, 112a) and the opposed surface (111b, 112b) for restricting heat flow through said sun blocker component (111, 112, 271, 301, 411,511, 611, 811,921, 951, 1800, 2100, 2700, 3100, 3200) between said sun-facing surface (111a, 112a) and said opposed surface (111b, 112b).
2. A spacecraft as claimed in claim 1, wherein the sun-facing surface (111a, 112a) is thermally insulated from

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- 3100, 3200) is further adapted for achieving a high radiation view factor from the thermal radiator surface (11,12,1804, 2121, 2721) to deep space by means including
5 a dimension and/or a shape of said sun blocker component (111, 112, 271, 301, 411,511, 611, 811,921, 951, 1800, 2100, 2700, 3100, 3200), in an operational configuration, serving to limit a corresponding geometric radiation view factor from said thermal radiator surface (11,12,1804,
10 2121, 2721) to deep space.
6. A spacecraft as claimed in any of the preceding claims, wherein an effective radiation view factor for thermal radiation from the thermal radiator surface (11,12,1804, 2121,2721) to deep space is significantly
15 greater than a corresponding geometrical radiation view factor to deep space, and in particular, for a geostationary spacecraft where the geometrical radiation view factor to deep space is 0.65, the effective radiation view factor to deep space is at least 0.87.

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7. A spacecraft as claimed in any of the preceding claims , wherein the sun-facing surface (111a, 112a) has
5 a low solar energy absorptivity of less than 0.5.
8. A spacecraft as claimed in any of the preceding claims , wherein the sun-facing surface (111a,112a) includes a solar cell panel for supplying electrical power to the spacecraft.
- 10 9. A spacecraft as claimed in any of the preceding claims, wherein the sun-facing surface (111a, 112a) has a high thermal emissivity of higher than 0.7.
10. A spacecraft as claimed in any of the preceding claims, wherein the sun ray blocker device (582, 681,
15 682) is adapted for a reconfiguration involving movement between a stowed, non-operative position and a deployed, operative position after launch of said spacecraft.
11. A spacecraft as claimed in any of the preceding claims, wherein the sun ray blocker device (581, 582,
20 681, 682) includes an attachment arm (207, 205, 430, 230, 1805, 1905, 2137, 2708, 2709) for attaching the sun blocker component (111, 112, 271, 301, 411,511, 611, 811,921, 951, 1800, 2100, 2700, 3100, 3200) to the spacecraft.

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the opposed surface (111b, 112b) by multi-layer insulation (MLI).

3. A spacecraft as claimed in any of the preceding
5 claims, wherein said sun blocker component (111, 112, 271, 301, 411, 511, 611, 811, 921, 951, 1800, 2100, 2700, 3100, 3200) is further adapted for achieving a high radiation view factor from the thermal radiator surface (11, 12, 1804, 2121, 2721) to deep space by means including
10 a region of said opposed surface (111b, 112b) being adapted to lie, in an operational configuration, substantially in a plane for limiting a radiation view factor from said opposed surface (111b, 112b) to said opposed surface (111b, 112b).
- 15 4. A spacecraft as claimed in any of the preceding claims, wherein said sun blocker component (111, 112, 271, 301, 411, 511, 611, 811, 921, 951, 1800, 2100, 2700, 3100, 3200) is further adapted for achieving a high radiation view factor from the thermal radiator surface
20 (11, 12, 1804, 2121, 2721) to deep space by means including a region of said opposed surface (111b, 112b) being adapted to face, in an operational configuration, at an angle away from said thermal radiator surface (11, 12, 1804, 2121, 2721) for limiting reflection by said
25 sun blocker component (111, 112, 271, 301, 411, 511, 611, 811, 921, 951, 1800, 2100, 2700, 3100, 3200) of thermal energy from said thermal radiator surface (11, 12, 1804, 2121, 2721) back to said thermal radiator surface (11, 12, 1804, 2121, 2721).
- 30 5. A spacecraft as claimed in any of the preceding claims, wherein said sun blocker component (111, 112, 271, 301, 411, 511, 611, 811, 921, 951, 1800, 2100, 2700,

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12. A spacecraft as claimed in claim 11, wherein the attachment arm (207, 205, 430, 230, 1805, 1905, 2137, 2708, 2709) is attached by a hinge means (203, 309, 406, 606, 306, 1812, 2138, 2710, 2711) to the sun blocker
5 component (111, 112, 271, 301, 411, 511, 611, 811, 921, 951, 1800, 2100, 2700, 3100, 3200) and/or by a second hinge means (215, 217, 407, 507, 607, 307, 1813, 1913, 2136, 2702, 2703) to the spacecraft.
13. A spacecraft as claimed in any of claims 10 to 12,
10 wherein the sun ray blocker device (581, 582, 681, 682) includes a motor for moving said sun ray blocker device between the stowed position and the deployed position.
14. A spacecraft as claimed in any of the preceding claims, wherein locating means are provided for locating
15 the sun ray blocker device (581, 582, 681, 682) with respect to the thermal radiator surface (11, 12, 1804, 2121, 2721) which includes adjustment means to maintain up to the whole of said thermal radiator surface in shadow irrespective of changes in the attitude and/or
20 orbital position and/or orbit of the spacecraft during normal operations.
15. A spacecraft as claimed in claim 14, wherein the adjustment means includes a variable length attachment

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arm (2130, 2730) for attachment of the sun blocker component to the spacecraft.

⁵ 16. A spacecraft as claimed in claim 15, wherein the attachment arm is a scissors arm (2730).

14. 17. A spacecraft as claimed in claim 15, wherein the attachment arm (2130) is formed of articulated portions (2132, 2134, 2137) which may be mutually articulated

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during rotation to vary an effective length of the attachment arm.

18. A spacecraft as claimed in claim 14, wherein the adjustment means includes carriage means (1801, 1902, 5 1906, 1907, 2001) for carrying the sun blocker component (1800) and transport means (1802, 1830, 1903, 1930, 2002, 2003, 2030) for moving the carriage with respect to the spacecraft.
19. A spacecraft as claimed in claim 18, wherein the 10 transport means includes guide means (1802) and the carriage means (1801) includes drive means (1830) to drive the carriage along the guide means.
20. A spacecraft as claimed in claim 18, wherein the 15 transport means includes guide means (2002) and motive means (2003) that are external to and connected to the carriage means (2001), the external motive means being driven by drive means (2030) to move the carriage means along the guide means (2002).
21. A spacecraft as claimed in claim 18, wherein the 20 carriage means includes an annulus (1902) rotatable in a circular path defined by bearing means (1903) the annulus being driveable by drive means (1930) to move the carriage along the path defined by the bearing means.
22. A spacecraft as claimed in any of claims 14 to 21, 25 having a solar cell array (100, 101, 225, 408, 2000) adapted for tracking movements of the Sun relative to the spacecraft, wherein the adjustment of the location of the sun ray blocker device (581, 582, 681, 682) in relation to the thermal radiator surface (11, 12, 1804, 2121, 30 2721) is synchronised with the

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23. A spacecraft as claimed in claim 22, wherein the sun ray blocker device (581, 582, 681, 682) is mounted on the solar cell array (100, 101, 225, 408) or on means carrying said solar cell array.
- ⁵ 24. A spacecraft as claimed in claims 22 or 23, wherein the solar cell array is adapted for tracking the movement of the Sun by rotation of the solar cell array about an axis of rotation of the solar cell array (100, 101, 225, 408, 2000) such

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that the sun blocker component (111, 112; 271; 301; 411; 511; 611; 811; 921; 951; 2100; 2700; 3100; 3200) also rotates about said axis of rotation of the solar cell array.

- 5 25. A spacecraft as claimed in claim 24, wherein the thermal radiator surface (11, 12, 2121, 2721) is orthogonal to the axis of rotation of the solar cell array so that the sun blocker component (111, 112; 271; 301; 411; 511; 611; 811; 921; 951; 2100; 2700; 3100; 10 3200) rotates about an axis normal to the thermal radiator surface.
26. A spacecraft as claimed in any of claims 23 to 25, wherein the adjustment means for attachment of the sun blocker component (2100, 2700) to a solar cell array 15 assembly (2131, 2701) are such that a distance between the sun blocker component and the solar cell array assembly may be varied during rotation of the sun blocker component.
27. A spacecraft as claimed in any of claims 14 to 26, 20 wherein the sun blocker device (581, 582, 681, 682) tracks the movement of the sun by rotation of the sun blocker device about an axis of rotation of the sun blocker device which is orthogonal to the thermal radiator surface (11, 12, 1804, 2121, 2721) so that the sun 25 blocker component (111, 112, 271, 301, 411, 511, 611, 811, 921, 951, 1800, 2100, 2700, 3100, 3200) rotates about an axis normal to said thermal radiator surface.

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28. A spacecraft as claimed in any of the preceding claims, wherein means (929, 931, 925, 927, 955, 957) are provided for adjusting the form and/or size of the sun
5 blocker component (111, 112, 271, 301, 411, 511, 611, 811, 921, 951, 1800, 2100, 2700, 3100, 3200).

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29. A spacecraft as claimed in any of the preceding claims,
including control means for controlling the spacecraft so
as to maintain an angle between a sun line and the

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thermal radiator surface (11,12, 1804, 2121, 2721) below a predetermined angle by adjustment of the orbit and/or attitude of the spacecraft in use.

30. A spacecraft as claimed in claim 29, wherein the
5 predetermined angle is 60 degrees.
31. A spacecraft as claimed in claims 29 or 30, wherein the control means is adapted to maintain the thermal radiator surface (11,12, 1804, 2121, 2721) substantially parallel to a plane of an orbit of the spacecraft.
- 10 32. A spacecraft as claimed in any of claims 29 to 31, wherein the control means is adapted to maintain the spacecraft in a sun synchronous orbit.
33. A spacecraft as claimed in any of claims 29 to 31, wherein the control means is adapted to maintain the
15 spacecraft in an equatorial or low-inclination orbit.

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SPACECRAFT

5 The present invention relates to a spacecraft and particularly to a spacecraft having a sun ray blocker device for shading thermal radiator surfaces on said spacecraft from solar heating.

10 The following patents are generally representative of the prior art in the broad fields of solar array related sun shields, solar array deployment mechanisms, and the thermal control of radiator surfaces for various types of spacecraft.

15 United States Patent 4,133,502 to Andrew Anchutin describes a plurality of arrays of solar cells which are symmetrically stored about a spacecraft during launch to provide symmetrical loading. When the spacecraft is in operational configuration, the solar arrays are deployed adjacent each other on one side of the spacecraft to effectively form a single array and the single array may be oriented to face the Sun by a common drive mechanism.

25 United States Patent 4,508,297 to Guy G. Mouilhayrat et al, describes an equatorial orbit satellite with solar panels having blades with a median line inclined at a certain angle relative to the equatorial plane. Thus, the field of vision of the antennas is free and disturbing torques become acceptable.

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United States Patent Number 5,372,183 to Harold P. Strickberger describes a spacecraft adapted for operation

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in a low inclination angle earth orbit which comprises north, south, east and west panels defining a spacecraft interior volume. The north and south panels are oppositely disposed with respect to each other and the east and west panels are oppositely disposed with respect to each other. The spacecraft interior volume generally and preferably lacks structural elements that substantially restrict thermal radiation among the panels. The north and south panels, to which spacecraft equipment is usually mounted, each include conductive heat pipes for reducing the temperature difference across each panel. The exterior surfaces of the north, south, east and west panels have a covering, preferably of optical solar reflectors (OSRs), for radiating thermal energy therefrom, wherein the OSRs have a solar absorptivity that is substantially less than their thermal emissivity. The interior surfaces of the north, south, east and west panels have a covering for effectively radiating thermal energy between and among the panels across the interior volume.

United States Patent 4,725,023 to Haruo Shiki describes a geostatic satellite which comprises a spinning drum for stabilization which spins around an axis of rotation which is parallel to the axis of the Earth. A paddle member loaded with solar cells is directly rotatable about the same axis and is controlled such that the solar cells face the Sun. A de-spun platform supports communication gear and maintains the gear pointed to a relatively fixed point on Earth. A shading device for shading the electronics laden de-spun platform from the Sun is attached to the paddle member

and rotatable therewith. Thereby, the shading device will always be disposed between the Sun and the de-spun platform. However, the shading device also blocks thermal radiation from the platform and also itself heats up in sunlight and radiates heat towards the platform, decreasing the efficiencies of heat transfer from the spacecraft to space.

Notwithstanding the prior art, the present invention is neither taught nor rendered obvious thereby.

It is an object of this invention substantially to reduce or eliminate the direct and indirect solar heating of certain spacecraft radiator-panels, and to also minimize the magnitude of any reduction in the radiative-view-factor of the (shielded) radiator panel. In order to achieve that objective, the materials and design selected for the sun ray blocker device, which will be discussed below, should ideally provide all of the following: minimum blockage of the field-of-view to deep space of its associated radiator surface(s), low absorption of the solar energy incident on its front (sunward) surface, high radiation of absorbed thermal energy back to space, and high insulation of heat between the front (sunward) and back (anti-sunward) sides of the sun ray blocker device.

It is also desirable to provide a sun ray blocker device that is capable of greatly reducing or eliminating solar energy incident on those sides of certain spacecraft relative to which the Sun direction makes a low angle. The types of spacecraft to which the present

invention applies include some spacecraft for operation in equatorial or low inclination orbits, and in sun synchronous orbits with low orbit-sun angles. In the case of three-axis stabilized, Earth-pointing, geostationary spacecraft for example, these shaded sides are either or both of the north and south main-body panels. In the case of the sun synchronous spacecraft for example, the shaded sides are either or both of the sides or main-body panels that face out along the pitch axis (i.e. that face parallel to the orbit normal and anti-normal). The present invention can also be applied to types of spacecraft, other than geostationary and sun synchronous types, upon which the solar illumination is incident at low angles relative to thermal radiator surface. In those spacecraft it is those main thermal radiator surface that can be shaded by the present invention device.

According to a first embodiment of the invention there is provided a spacecraft for orbiting a sunlit celestial body, the spacecraft including a thermal radiator surface for radiating heat from the spacecraft into space, and a sun-ray blocker device mounted on said spacecraft for shielding said thermal radiator surface from rays of sunlight, characterised in that said sun ray blocker device is locatable for placing in shadow substantially the whole of the thermal radiator surface from sunlight without substantially impeding thermal radiation from said thermal radiator surface into space.

Preferably an effective radiation view factor for thermal radiation from the thermal radiator surface

(11,12,1804, 2121,2721) to deep space is significantly greater than corresponding geometrical radiation view factor to deep space, and in particular, for a geostationary spacecraft where the geometrical radiation view factor to deep space is 0.65, the effective radiation view factor to deep space is at least 0.87.

A preferred inventive feature will be seen to reside in the sun ray blocker device including at least one sun blocker panel having a sun-facing surface and an opposed anti-sun-facing surface, wherein the sun-facing surface is thermally insulated from the opposed surface.

conveniently the sun-facing surface is thermally insulated from the opposed surface by a multi-layer insulation blanket.

Advantageously the sun-facing surface has a low solar energy absorptivity of less than 0.5.

Advantageously the sun-facing surface includes a solar cell panel for supplying electrical power to the spacecraft.

Preferably the sun-facing surface has a high thermal emissivity of higher than 0.7.

A preferred inventive feature will be seen to reside in the sun ray blocker device being moveable between a stowed, non-operative position and a deployed operative position.

Conveniently the sun ray blocker device includes an attachment arm for attaching the sun blocker panel to the spacecraft.

Advantageously the attachment arm is attached by a hinge means to the sun blocker panel and/or by a second hinge means to the spacecraft.

Advantageously the sun ray blocker device includes a
5 motor for moving the sun ray blocker device between the stowed position and the deployed position.

Preferably locating means are provided for locating the sun ray blocker device with respect to the thermal radiator surface which include adjustment means to
10 maintain the majority of the thermal radiator surface in shadow irrespective of changes in the attitude and/or orbit of the spacecraft.

Advantageously the adjustment means includes carriage means (1801, 1901, 2001) for carrying the sun
15 blocker panel (1800, 1900, 2000) and transport means (1802, 1808, 1903, 1904, 2003, 2006) for moving the carriage with respect to the spacecraft.

Conveniently the transport means includes rail means (1802) and the carriage means (1801) includes drive means
20 to drive the carriage along the rail means.

Preferably the transport means includes an annulus rotatable in circular path defined by bearing means, the annulus being driveable by drive means to move the carriage along the path defined by the bearing means.

Alternatively the transport means includes rail
25 means (1902) and belt means (1903) connected to the carriage means (1901), the belt means being driven by

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drive means (1904) to move the carriage means along the rail means (1902).

Conveniently the adjustment means includes a variable length attachment arm (2101, 2703) for attachment
5 of the sun blocker panel (2100, 2700) to a solar cell array assembly (2103, 2701) for rotation with the solar cell array assembly, such that the distance of the sun blocker panel from the solar cell array assembly may be varied during rotation.

10 Alternatively the spacecraft has a solar cell array adapted for tracking movements of the sun relative to the spacecraft, wherein the adjustment of the location of the sun ray blocker device in relation to the thermal radiator surface is synchronised with the tracking
15 movement of the solar cell array, when in normal operation.

Conveniently the sun ray blocker device is mounted on the solar cell array or on means carry said solar cell array.

20 Advantageously the solar cell array tracks the movement of the sun by rotation of the solar cell array about an axis of rotation of the solar cell array such that the sun blocker panel also rotates about said axis of rotation of the solar cell array.

25 Conveniently the thermal radiator surface is orthogonal to the axis of rotation of the solar cell array so that the sun blocker panel rotates about an axis normal to the thermal radiator surface.

Advantageously adjustment means includes a variable length attachment arm for attachment of the sun blocker panel to the spacecraft.

5 Advantageously the attachment arm is a scissor arm (2703).

Alternatively the attachment arm (2101) is formed of articulated portions (2104, 2105, 2106) which may be mutually articulated during rotation to vary an effective length of the attachment arm.

10 Conveniently adjustment means for attachment of the sun blocker panel to a solar cell array assembly are such that a distance between the sun blocker panel and the solar cell array assembly may be varied during rotation of the sun blocker panel.

15 Conveniently means are provided for adjusting the size of the sun blocker panel.

Conveniently the spacecraft includes control means for controlling the spacecraft so as to maintain an angle between a sun line and the thermal radiator surface below
20 a predetermined angle by adjustment of the orbit and/or attitude of the spacecraft in use.

Preferably the predetermined angle is 60 degrees.

More preferably the predetermined angle is 45 degrees.

25 Most preferably the predetermined angle is 23.5 degrees.

Advantageously the control means is adapted to maintain the thermal radiator surface substantially parallel to a plane of an orbit of the spacecraft.

Alternatively the control means is adapted to
5 maintain the spacecraft in a sun synchronous orbit.

Alternatively, the control means is adapted to maintain the spacecraft in an equatorial or low-inclination orbit.

According to another embodiment of the invention
10 there is provided in a three axis stabilised spacecraft for orbiting about a planet and having at least one solar cell assembly having at least one solar cell panel, and being a north solar cell panel assembly or a south solar cell panel assembly, said at least one solar cell panel
15 assembly being mounted on an axle so as to be controllably rotated from said spacecraft about an axis of rotation so as to face the sun, said spacecraft having a nadir panel which is generally pointing to the centre of the planet, an opposite panel known as a zenith panel,
20 which faces away from the centre of the planet and sharing the same planar normal vector as said nadir panel, an east panel and a west panel, said east panel and said west panel having their planar normal vector laying on a orbital plane pointing to the velocity vector
25 of the spacecraft generally tangential to the direction of travel on the orbit, and a north panel and a south panel, said north panel and said south panel having their planar normal vector generally perpendicular to the orbit plane and parallel to the axis of rotation of the planet,

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said solar cell panel extending outwardly from said spacecraft, the improvement which comprises:

attaching at least one sun ray blocker device to said at least one solar cell panel, said at least one device being either a north blocker device or being a south blocker device and corresponding to said at least one solar cell panel, each of said at least one sun ray blocker device being positioned forwardly from and offset relative to a solar cell surface of a solar cell panel and at a predetermined angle to either of said north panel and said south panel, said north panel or said south panel, said sun ray blocker device being positioned so as to cast a shadow on at least a majority of the exposed surface of its corresponding north or south panel during solar exposure thereto.

According to another embodiment of the invention there is provided in a three axis stabilised low inclination orbit spacecraft for orbiting about the earth and having two sets of solar cell array assemblies having solar cell arrays, one set being a north solar array assembly and the other being a south solar array assembly, said assemblies each being mounted on an axle so as to be controllably rotated from said spacecraft about an axis of rotation so as to face the sun, said spacecraft having an earth panel which is generally pointing to the centre of the earth, an opposite panel known as a zenith panel, which faces away from the centre of the earth and sharing the same planar normal vector as said earth panel, an east panel and a west panel, said east panel and said west panel having their planar normal vector laying on an orbital plane pointing to the

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velocity vector of the spacecraft generally tangential to the direction of travel on the orbit, and a north panel and a south panel, said north panel and said south panel having their planar normal vector generally perpendicular to the orbit plane and parallel to the axis of rotation of the earth, said solar cell panel extending outwardly from said spacecraft, the improvement which comprises:

5 attaching at least one sun ray blocker device to each of said north solar array and said south solar array, one device being a north device and another device being a south device, each of said sun ray blocker devices being in the form of a panel and being positioned forwardly and offset relative to the solar cell surface of a solar ray and at a predetermined angle to said north panel and said south panel, said north blocker device being positioned so as to cast a shadow on at least a majority of the exposed surface of said north panel during solar exposure thereto, and said south blocker device being positioned so as to cast a shadow on the exposed surface of said south panel during solar exposure thereto.

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25 The present invention preferably provides a sun-synchronous sun ray blocker device (not to be confused with sun synchronous orbits referred to elsewhere herein) for use in a spacecraft designed to orbit around a planet with solar incidence at low angles to their thermal radiator surfaces, i.e. with sun directions close to the planes of the individual radiator surfaces.

30 Preferred embodiments of the present invention are spacecraft for operating in an orbit plane oriented at a

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low angle (or within a range of low angles) to the sun direction, the said spacecraft having a thermal radiator surface that is oriented approximately parallel to the orbit plane and a solar array assembly that is rotated
5 about an axis approximately perpendicular to the orbit plane nominally at the orbital rate. Examples of appropriate orbits are: (a) low inclination orbits around the Earth (including nominally equatorial orbits), and
10 (b) sun synchronous orbits with low orbit-sun angles (which around Earth and Mars, for example, are nominally polar orbits). The term "spacecraft" as used herein includes satellites and other space bound vehicles.

Mounted on any spacecraft to which the present
15 invention is applied is at least one device for blocker sun rays and thereby preventing them from directly impinging on a radiator surfaces of the spacecraft.

In many embodiments of the present invention the
20 individual spacecraft will have at least one solar array assembly (comprised of solar cell panels and rotary axial booms) which may be used as mounting support for the sun ray blocker device(s), so that the combination assembly of solar array assembly and sun blocker device(s) is
25 operationally controllably rotated together as an integral unit to track the Sun throughout the orbital revolutions of the spacecraft, said solar array assembly being mounted on the spacecraft so that operationally in orbit it can be rotated about an axis that is maintained
30 oriented approximately perpendicular to the orbit plane in a manner such that the solar-cell side of the solar cell panels is maintained sun facing and substantially

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perpendicular to the Sun direction. Because then the sun ray blocker device may rotate integrally with the solar array assembly, it is able to prevent sun rays from directly impinging on all or part of an associated thermal radiator surface(s), whose plane is maintained approximately parallel to the orbit plane, thus creating a continuous steady and benign thermal environment for the thermal radiator surface.

Spacecraft operated in orbits with low orbit-Sun angles (the angle between the orbit plane and the Sun) are prime candidates for application of the current invention device. Various different frequently-utilized types of orbits feature low orbit-Sun angles. Currently, among the most utilized types of orbits with low orbit-Sun angles are (a) low inclination and nominally-equatorial orbits, including geosynchronous orbits, and (b) the subset of sun synchronous orbits with low orbit-Sun angles. Sun synchronous orbits maintain a little-varying orbit-Sun angle as the planet revolves around the Sun. The Earth revolves around the Sun once per year.

One type of spacecraft operated in a nominally equatorial orbit around a planet, e.g. the Earth, or in particular, a geosynchronous orbit, is frequently used for the purposes of telecommunications, broadcasting, monitoring ecological conditions, global positioning, remote sensing, surveillance and weather forecasting.

Another type of satellite operated in nominally sun synchronous orbits around planets, e.g. the Earth, with low orbit-Sun angles, is frequently used for the purposes

of weather monitoring and remote sensing of the planet and its atmosphere. Some of the benefits of these sun synchronous orbits are: low spacecraft altitudes, frequent over-flight of the planet within close proximity of virtually all latitudes and longitudes, and near constant angle of solar illumination on the day side of the orbit.

Means of adjusting the attitude and orbit of spacecraft are well known, for example, are described in "Principals of Communication Satellites" by Gary D Gordan and Walter L Morgan published by John Wiley & Sons 1993, pages 12-14, 55-58 and in "Spacecraft Attitudes, Termination and Control" by James R Wertz published by Kluwer Academic Publishers 1978. Attitude and orbit control may for example be provided by the use of thrusters and/or momentum or reaction wheels.

Typically, the attitude (i.e. the orientation) of these types of satellite is controlled so that as the satellite orbits the planet part of its payload equipment steadily faces approximately toward the center of the planet, while the solar arrays are maintained sun pointing. The attitude (orientation) control systems of such spacecraft belong to various classifications that are well known within the space industry. For example, two of the more currently prominent types of attitude control system are commonly referred to as "three-axis-stabilized" control systems and "spin stabilized" control systems. The present invention device functions independently of the type of attitude control system, and independently of the orientation of spacecraft equipment

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other than the orientation of the thermal radiator surfaces that the device shields from solar energy. In these types of spacecraft, the performance of the present invention device is generally better the closer the shadowed thermal radiator surface is to being parallel to the orbit plane (which in these types of spacecraft is maintainable at a low angle to the sun line).

Hereinafter, the concept of a "model spacecraft" is defined and employed in order to avoid the distraction of multiple lengthy descriptions of diverse spacecraft to which the present invention device may be applied. The model spacecraft is used herein, somewhat like a tailor's dummy, in order to facilitate the illustration and explanation of features, functions, and examples of applications of the present invention device.

By definition the model spacecraft has a basic, deployed (i.e. unfolded), structural configuration that is typical of many current three axis stabilized satellites, and a corresponding operational mode that is typical of a geostationary Earthpointing spacecraft. Note that this definition was selected on the basis of current estimates of the most frequent future application of the present invention device. The definition of the model spacecraft could equally well have been based on typical characteristics of another relevant type of spacecraft, for example an Earth-pointing spacecraft in a sun synchronous orbit with a low orbit-Sun angle.

Referring to FIGURES 1 and 5, the basic structural configuration of the model spacecraft is based on a main body in the form of a hollow, right parallelepiped. For

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the stated purposes of using the concept of the "model spacecraft" herein, it is useful to consider the main body as being comprised of six principal, planar, structural panels. The external surfaces of one opposing pair of the six panels that form the main body of the model spacecraft constitute the mounting sites for the thermal radiator surfaces that are shielded from direct solar heating by means of the present invention device. Mounted on one or each of these two radiator-bearing panels, and extending perpendicularly outwards therefrom, is a solar array assembly, comprised of a rotary solar array boom to which are attached solar cell panels.

That is not to say that application of the present invention device is limited to spacecraft resembling the structural configuration and operational mode of the model spacecraft. For example, the present invention device is also applicable to: sun synchronous spacecraft in orbits with low orbit-Sun angles; spin stabilized spacecraft; spacecraft with polyhedral and/or irregular structures; spacecraft that are not nadir pointing; spacecraft with solar arrays that deploy and subsequently lie along axes that are not perpendicular to the radiator-bearing panels; etc.

Much of the text herein that supports the accompanying claims is written with reference to the model spacecraft. Regardless, the supporting text also applies to applications of the present invention device to other suitable types of spacecraft. For example, the principal relevant difference between many suitable sun synchronous spacecraft (for polar orbits at Earth and

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Mars at least, where the polar axes lie close to the planes of sun-synchronous orbits around them) and the model spacecraft is that the plane of the thermal-radiator surface(s) that is shaded by the present invention device is approximately parallel to the axis of rotation of the planet (rather than perpendicular to the axis of rotation of the planet as for geostationary spacecraft like the model spacecraft). Accordingly, the supporting text describing spacecraft like the model spacecraft is easily read as it relates to these suitable sun synchronous spacecraft, for example by substituting in "pitch axis panel" or "orbit normal panel" to replace "north/south panel", and substituting in "velocity panel" or "roll axis panel" to replace "east/west panel".

In order to provide functional services in an operational orbit, the model spacecraft has one of the six structural panels of its main body continuously facing the planet, e.g. the Earth. That panel is referred to as the earth panel or the nadir panel. A vector that is outward-from and normal-to the earth panel is parallel to the (body fixed) yaw axis of the spacecraft. In the model spacecraft the yaw axis is maintained nominally parallel to the nadir direction, i.e. is nominally pointed toward the center of the planet. Because the model spacecraft operates in a geosynchronous orbit, which is nominally circular, the yaw axis of the model spacecraft is maintained nominally perpendicular to the velocity vector of the spacecraft. A vector that is outward-from and normal-to the plane of the structural panel opposite the nadir panel is parallel to the negative yaw axis. That main-body panel of three

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axis stabilised Earth pointing geostationary spacecraft like the model spacecraft is usually referred to as the zenith panel or anti-earth panel.

5 Another opposing pair out of the six structural panels comprising the main body of the model spacecraft are oriented so that, nominally or approximately, vectors that are outward-from and normal-to their planes lie in the orbital plane and are perpendicular to the yaw axis
10 and to the nadir and zenith directions. These outward normal vectors are parallel and anti-parallel to the positive and negative (body fixed) roll axes of the spacecraft. Because the geosynchronous orbit of the
15 model spacecraft is circular, the roll axes of the model spacecraft nominally coincide with the velocity and anti-velocity vectors of the orbital motion. For
geostationary spacecraft the velocity of the spacecraft is eastward; and consequently these two main-body panels
20 of spacecraft like the model spacecraft are generally referred to as the east and west panels.

 Accordingly, the remaining two structural panels comprising the main body of the model spacecraft are oriented so that their planes are nominally or
25 approximately parallel to the orbit plane. Vectors that are outward-from and normal-to the planes of these panels are parallel to the positive and negative (body fixed) pitch axes of the spacecraft. Since the geosynchronous orbit of the model spacecraft is nominally equatorial,
30 the pitch axes of the model spacecraft are approximately parallel and anti-parallel to the spin axis of the Earth; and accordingly these two main-body panels of spacecraft

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like the model spacecraft are referred to as the north and south panels.

To avoid unnecessary further repetition, to
5 illustrate and explain the features and functions of the
present invention device, reference shall be made to
application to the (previously defined) model satellite,
which is operated in a three-axis-stabilized, Earth-
pointing, geosynchronous mode. (That is not to say that
10 application of the present invention device is limited to
spacecraft that resemble the previously described model
spacecraft and/or are operated in the corresponding mode.
For example, the present invention device is also
applicable to spin stabilized spacecraft with irregularly
15 shaped structures that are neither nadir pointed nor
geosynchronous.)

Through each orbital revolution of a spacecraft like
the model spacecraft, which in a preferred embodiment is
20 around the Earth, the Sun sequentially directly
illuminates the east, zenith, west, and nadir main-body
panels. While illuminated (or insolated) thus these main-
body panels absorb incident solar energy and their
temperatures increase, which significantly reduces their
25 net radiative cooling capability. If not countered by
some means this can significantly limit the quantity of
equipment (which dissipate heat into the spacecraft) that
can be carried on board, and/or can result in undesirably
elevated temperatures of associated spacecraft equipment.
30 The north and south panels, however, generally face deep
space during the entire orbit and only directly receive
solar illumination and solar energy at relatively low

incidence angles on a seasonal basis. Because the direct input of solar energy into the north and south panels is relatively low to zero, these panels are the principal sites on spacecraft like the model spacecraft for the locations of thermal-energy radiator surfaces. The north panel is directly heated by the sun for a duration of about 6 months (from about March 21st to about October 21st) at an incidence angle, defined as the angle between the panel plane and the sun vector, which seasonally increases from 0 degrees (when the sun vector is edge-on to the panel) to about 23.5 degrees followed by a decrease to 0 degrees again while the Sun is on the north side of the earth equator, i.e. during the northern spring and summer. The south panel is directly heated by the Sun for the remainder of the year, i.e. during the southern spring and summer, in a similar fashion and concomitantly with the north panel. These relatively low solar incidence angles favor use of the north and south panels for locating the principal thermal radiator surfaces of the spacecraft. At a maximum incidence angle of 23.5 degrees for the solar vector relative to the north and south panels the incident solar energy is approximately 40% of that for normal (perpendicular) incidence.

25

In the prior art numerous design practices have been employed to the surface treatment of the north and south panels in an effort to reduce the absorbed solar energy, thereby allowing more internal heat dissipation without raising the operational temperature level of the equipment that is thermally coupled to the panels. One example, optical surface reflectors (OSRs), which have a

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high ratio of thermal emissivity versus solar absorptivity, have been widely used as the surface treatment of spacecraft thermal radiators. However, the seasonal solar heating of the spacecraft through OSRs
 5 still constitutes a significant amount of heat input to the spacecraft, which forces the spacecraft designer to lower the level of internal power dissipation to maintain an acceptable operating temperature for the spacecraft equipments. Solar energy absorbed by a spacecraft like
 10 the model spacecraft through its north and south panels has two obvious undesirable impacts on the performance of the spacecraft.

(1) It reduces the allowable level of internal power
 15 dissipation, which directly relates to the "value" of a spacecraft. The revenue from a spacecraft, especially a commercial communications spacecraft, is fundamentally limited by its capacity for power dissipation. A reduced
 20 allowable power dissipation level directly results in lower potential for revenue generation, which reduces the value of the spacecraft.

(2) The operating temperatures of the internal
 25 equipment are increased, and as a result the reliability of those components may be reduced. The reliability also relates to the life of a spacecraft, which directly relates to its "value" as well.

If the undesired solar heating were to be reduced,
 30 higher operational payload power would be allowable within the spacecraft and/or lower operating temperatures of the spacecraft equipments would be achieved.

Therefore, by virtue of the present invention, the spacecraft could be operated at a higher efficiency, with higher reliability, and would thereby generate revenue at a faster rate, all of which improvements would increase its value.

There is another important factor that affects the capability of a thermal radiator surface to reject heat to deep space: the "effective" radiative view factor (ranging from 0 to 1) from that panel to deep space. The ideal radiative-view-factor enabling a panel to reject maximum heat into deep space is unity (1). A device or means situated between the radiator surface and deep space could block the radiator's view to deep space and thus reduce the heat-radiating capability of the radiator.

The sun ray blocker device of this invention is mounted on the spacecraft, for example conveniently attached to the solar array assembly/assemblies of the spacecraft and rotating therewith. Since the primary function of the sun ray blocker device used in this invention is to provide a significantly more benign thermal environment for the principal thermal radiator surfaces (or panels), basically by shading them, the spacecraft should have at least one such surface. In the case of three-axis-stabilized Earth-pointing geostationary spacecraft, for example, there are two principal thermal radiator surfaces - the north and south panels; and accordingly at least two separate sun ray blocker devices can be included, one to shade each of these panels. Thus, the sun ray blocker device in the

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present invention follows the movement of the Sun with respect to the thermal radiator panel(s) that it shades. In the case of a three-axis-stabilized Earth-pointing geostationary spacecraft, like the model spacecraft for example, the sun ray blocker device casts its shadow onto its associated thermal radiator surface, which is on either a north or a south panel, seasonally - through the six month long northern spring and summer in the case of the north panel, and through the six month long southern spring and summer in the case of the south panel. The (counter-productive) reduction in the radiation-view-factor of the thermal radiator surface caused by the presence of the associated present invention device is small; and the net effect of this reduction combined with the (beneficial) shading of the panel is a great improvement in the radiative efficiency of the radiator surface.

In addition to the foregoing, some of the considerations, advantages and parameters for the present invention device are as follows (others will become self-evident from the subsequent discussion of the FIGURES):

Variety in the operational form and size of the sun ray blocker device is permissible provided that its sun blocker panel follows the movement of the Sun with respect to the spacecraft, and it blocks the Sun's rays by casting a shadow onto the spacecraft main body at appropriate times, and it produces close to the minimum reduction in the effective radiative view factor to deep space of the thermal radiator that it shields, and it

satisfies other system requirements of the spacecraft
(for example clear field of view requirements).

5 The material and/or the construction of the sun
blocker panel of the sun ray blocker device is preferably
highly thermally insulating between its sun and anti-sun
sides in order to provide the greatest practical
effective radiative view factor and radiative efficiency
of the radiator-surface shielded by the sun blocker
10 panel.

In its fully deployed configuration the sun blocker
panel may be mounted through a wide range of orientations
relative to the radiator surface that it shields (for
15 example, the angle 501 in FIGURE 12a below does not have
to be 90 degrees i.e. a right angle) as long as it casts
shadow providing adequate coverage of the associated
thermal radiator surface(s) on the spacecraft.

20 The ideal width of the sun blocker panel is greater
than either the width or the length of the radiator
surface that it shields. However, the dimensions of the
sun blocker panel may be limited by other constraints.
For example, in the launch configuration the folded
25 dimensions of the sun blocker panel may be limited by
launch-envelope constraints, i.e. the size of the volume
allowed for the spacecraft by the launch vehicle during
launch. Therefore, it may be necessary to make the sun
ray blocker panel deployable to enable it to be folded
30 for launch and deployed in orbit. This can be achieved by
hinged deployment, slide extension, pre-offset or any
other means to increase the width of the sun blocker

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panel (see FIGURES 16a, b and c, and 17a, b and c discussed below).

5 The mechanisms for extending, deploying, and supporting the sun blocker panel may involve various techniques and devices that are well known in the current state of the art of the design of mechanisms for spacecraft. For example the techniques and devices employed could involve mechanisms constructed from well known device types such as: hinges, flaps, slides, spring motors, wax motors, detentes, cable/bolt cutters, split nut releases, pin pullers, hook and pin releases, etc. Alternatively, so-called "active" devices such as electrical motors may be used at the discretion of the spacecraft designer. For example, one or more electrical motor (for example a stepper drive motor) could be employed to produce the motions resulting in extension (and possibly also retraction) of the sun blocker panel. Such active control could be utilized to facilitate certain operations of the spacecraft, for example station-keeping and attitude control operations for which displacing the sun blocker panel from the exhaust plume fields of rocket thrusters would be beneficial.

25 The present invention device is applicable to spacecraft other than those spacecraft, like the model spacecraft for example, which operate in the low-inclination or equatorial orbits that have been described thus far herein. It is applicable to the broad class of spacecraft for which the solar illumination (insolation) is incident at low angles relative to the planes of the surface(s) of their thermal-radiator surface(s).

A certain subset of spacecraft belonging to the set of spacecraft that are well known in the space industry as "sun synchronous" fulfill this requirement for low solar incidence angles on at least one thermal radiator surface; and the present invention is applicable to them. Within this subset of sun synchronous spacecraft is an even smaller but well known subset comprised of those spacecraft that operate in orbits with low orbit-Sun angles and in which the thermal radiator surfaces are utilized while oriented close to parallel to the orbit plane. A sun ray blocker device according to this invention is applicable to those spacecraft, to provide them with a shaded, benign, and desirable thermal environment for their thermal-radiator surfaces basically by protecting them against direct solar heating. Note, however, that when the angle of incidence of direct sunlight on the thermal radiator surface is zero the sun ray blocker device is unnecessary.

Heretofore the structural configuration and orientation of spacecraft to which the current invention device is applicable have mainly been described with reference to three-axis-stabilized Earth-pointing spacecraft for operating in low inclination or equatorial orbits, like the model spacecraft for example. The fundamental difference between those preceding descriptions and the structural configurations and orientations of the sun synchronous spacecraft to which the current invention device is applicable stems from the orientation of the orbit with respect to the axis of rotation of the planet. Within the space industry, sun

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synchronous orbits are widely referred to as being "polar", since the orbit plane of a sun synchronous orbit, around Earth and Mars at least, lies within several degrees of the axis of rotation of the planet; and therefore nominally includes the planetary poles. Therefore, for the aforementioned particular subset of sun synchronous spacecraft to which the current invention device is applicable, the panels and the radiator surfaces on them that are thermally protected by the current invention device are generally not, strictly speaking, "north" and "south" panels. However, herein the terms "north" and "south" are occasionally used for convenience to indicate the panels that are thermally protected by the sun blocker panel on spacecraft in sun synchronous orbits as well as on spacecraft like the model spacecraft, for example, in (nominally) equatorial orbits. The rationale is that in the particular, suitable, well known, and currently populous, aforementioned, subset of sun synchronous spacecraft the planes of thermal radiator panels shielded by the present invention device are also approximately perpendicular to the axis of the orbit (as for spacecraft like the model spacecraft in its orbital configuration and orientation). For both these types of spacecraft we could instead meaningfully refer to the protected panels and radiator surfaces as "pitch-axis" or "orbit normal" panels and surfaces, because the pitch axis of the spacecraft (which is parallel to the orbit normal) is nominally/approximately perpendicular to them and thereby defines their orientation.

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Depending upon the requirements of the propulsion subsystem and/or the attitude control subsystem of the spacecraft, the spacecraft designer may elect to provide only one sun ray blocker device, i.e. on only one of the two sides of the spacecraft that face approximately along the pitch axis (e.g. on the north or the south panel for the model spacecraft). In any particular application there may be a preference for one side of the spacecraft over the opposite side because of other system requirements. For example, in a potential embodiment of the present invention device on a particular current design of geostationary spacecraft, the south side is preferred because of field of view requirements for attitude-control thrusters on the north side.

Again, if the spacecraft designer elects to do so, solar cells can be mounted onto the external surfaces of the sun blocker panel to provide additional power to the spacecraft.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention should be more fully understood when the specification herein is taken in conjunction with the drawings appended hereto showing exemplary embodiments of the invention wherein:

FIGURE 1 is a simplified perspective view of a prior art three axis stabilized Earth-pointing geosynchronous spacecraft;

FIGURE 2 shows an east-panel based view of the prior art spacecraft illustrated in FIGURE 1 orbiting in a low inclination or an equatorial orbit;

5 FIGURE 3a shows a north-panel based, top view of the prior art spacecraft illustrated in FIGURE 1 orbiting about the Earth at different times of the day, and FIGURE 3b illustrates orbit-plane based views of that spacecraft at its noon, 6 a.m., and midnight positions and also
10 establishes sun angles for different seasons of the year;

FIGURES 4a and 4b show the variation in the solar incidence angle on the north and south panels, respectively, of the prior art spacecraft illustrated in
15 FIGURE 1 orbiting Earth, through one calendar year;

FIGURE 5 illustrates a perspective view of a spacecraft configuration according to the present invention, based on the prior art spacecraft illustrated
20 in FIGURE 1;

FIGURES 6a, 6b and 6c illustrate top views of a present invention arrangement as applied to the prior art spacecraft illustrated in FIGURE 1. The views shown are
25 simultaneously parallel to both the orbit-plane and the plane of the solar cell panels and the sun blocker panels of the sun ray blocker device. Hereinafter this view direction is also referred to as "top view". FIGURES 6a, 6b and 6c show that as the spacecraft revolves around the
30 orbit the earth panel always faces the Earth, and the cell-side of the solar array panels together with the

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front (sunward) sides of the sun blocker panels of the sun ray blocker devices always face the Sun;

FIGURES 7, 8 and 9 illustrate top views of present invention devices utilizing different attachment arrangements;

FIGURES 10a, 10b and 10c illustrate portions of top views of one of the solar array assemblies of a prior art spacecraft before, during, and after its deployment;

FIGURES 11a, 11b, 11c, 12a, and 12b show, in top view, aspects of the deployment and the function of present invention devices as applied to the prior art spacecraft shown in FIGURES 10a, 10b, and 10c;

FIGURES 13 and 14a show partial top views of two alternative present invention devices; and FIGURE 14b shows a partial back (anti-sun) side view of the arrangement shown in FIGURE 14a;

FIGURES 15a and 15b show partial top views of an alternative present invention device in its fully deployed and partially deployed configurations, respectively;

FIGURES 16a, b, and c show a view of an alternative present-invention device from the front (sunward) direction with the sun blocker panel fully deployed, and two views from a direction orthogonal to both the front view and the (previously defined) top view directions

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with the sun blocker panel folded and deployed,
respectively;

FIGURES 17a, b, and c show a different alternative
5 present-invention device in the same views and deployed
states as those shown in FIGURES 16a, b, and c;

FIGURE 18 shows a further embodiment of the
invention;

10

FIGURE 19 shows another embodiment of the invention;

FIGURE 20 shows another embodiment of the invention;

15

FIGURES 21 to 24 and 26 show another embodiment of
the invention;

FIGURE 25 shows details of the embodiments of
FIGURES 21 and 24 and 26;

20

FIGURES 27 to 30 show another embodiment of the
invention; and

FIGURES 31 and 32 illustrate alternative shapes for
25 sun blocker panels used in the present invention.

Referring now to FIGURE 1, there is shown an oblique
view of a fully deployed (i.e. fully unfolded from its
launch configuration) spacecraft (or satellite) 1, like
30 the previously described model spacecraft for example,
which is represented by a main body 10 which contains six
external panels: 11, 12, 13, 14, 15 and 16, a group of

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antenna reflectors 20, 21, 22 and 23, and two solar array assemblies, consisting of two solar arrays (one or more solar cell panel) 100 and 101 and their supports 100a and 101a by which they are connected to the main body 10, which are extended northward and southward from the main body out of the north and south panels 11 and 12, respectively. The number of antenna reflectors is driven by the need of the telecommunications application and is a matter of design. In this example, four reflectors are shown and are represented by two deployable large reflectors 20 and 21 mounted on east and west panels 15 and 16, respectively. Two non-deployable reflectors 22 and 23 are mounted on nadir panel 14. While orbiting in a low inclination orbit about Earth, the spacecraft is controlled in such a way that the earth or nadir panel 14 is pointing in the general direction of the center of the Earth, thus allowing the antenna reflectors to perform telecommunications functions with Earth. Opposite to the earth panel 14 is the zenith panel 13.

The solar arrays 100 and 101 may contain multiple panel elements (typically two to eight or more on each side - a four panel-element example is shown in FIGURE 1) or may contain as few as one panel element. However, usually solar arrays that are comprised of multiple solar cell panels are utilized, in order to provide sufficient electrical power for the spacecraft's use. The size and number of the solar cell panels is driven by mission power requirements, and is constrained by, among other factors, the capability of the attitude control subsystem to maintain pointing stability and also by the capability of the thermal control subsystem to manage the heat

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dissipated on board the spacecraft. Once the size and number of the panel elements is defined, generally it is desired to maximize the electrical power generated by the solar cells which are mounted on one side of the array panels by facing the cell side of the array toward the Sun as directly and as long and continuously as possible. With spacecraft main body 10 maintaining its earth panel 14 pointing to the Earth continuously, the line between the spacecraft and the Sun will cone around the north-south axis of a spacecraft like the model spacecraft once every orbit, making the Sun appear to circle about the main body 10 as it does so. In order to maintain both solar arrays of a spacecraft like the model spacecraft pointing directly to the Sun they are driven by motor systems which rotate the arrays about the north-south axis, as indicated by the arrow R in FIGURE 5 with respect to the main body 10 at a speed such that the cell side of the array always faces the Sun while the spacecraft orbits the Earth, i.e. the solar arrays rotate about the north-south axis sun synchronously with the Sun to achieve optimum sun exposure for maximum power generation.

Reference is made to FIGURE 2, a top view of prior art spacecraft or satellite 1 of FIGURE 1, wherein the aforesaid seasonal exposures are illustrated. (Parts identical or very similar to those in FIGURE 1 are identically numbered throughout the FIGURES herein and are not all repeated, to reduce redundancy. This applies to all of the following FIGURES that illustrate the same spacecraft or the same parts or components, or ones very similar.) The north panel 11 and the south panel 12

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(FIGURES 1 and 2) are maintained oriented parallel to the orbital plane of the satellite, which is co-planar or nearly co-planar with the equatorial plane of the Earth. While the spacecraft is orbiting the Earth, these panels (11 and 12) will not receive daily solar input like the other panels (earth panel 14, zenith panel 13, east panel 15 and west panel 16). Those two panels 11 and 12, however, will be subjected to direct solar heating on a seasonal basis, at incidence angles which will peak at 23.5 degree at the northern summer- and northern winter-solstices respectively, as shown.

FIGURE 3a shows a north-based top view of a spacecraft 1 orbiting Earth at different local times of day and illustrates the constancy with which the nadir panel 14 faces Earth 300 throughout the orbital revolutions. (The solar cell panels are shown edge-on out of the paper.)

FIGURE 3b shows a partial side view of the spacecraft 1 of FIGURES 1 and 2 at midnight, 6 a.m., and noon orbital positions, and also the approximate sun angles at the northern summer and northern winter solstices at midnight and noon.

FIGURES 4a and 4b show the profile of the solar incidence angle on the north and south panels, respectively, such as panels 11 and 12 of spacecraft 1 shown in FIGURE 1, for one calendar year.

It can be seen from FIGURES 4a and b that sunlight is incident on each of the north panel and south panel

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for a portion of the calendar year. These periods are nominally 21 March through 21 September for the north panel, and 21 September through 21 March for the south panel. Therefore, the sun ray blocker devices of the
 5 current invention perform their shading functions for their respective radiator panels for those periods only.

FIGURE 5 illustrates one preferred embodiment of the current invention, which eliminates or greatly reduces
 10 the seasonal solar input on the north and south panels 11 and 12, thus providing more efficient thermal radiators for the spacecraft.

In this present invention embodiment, the sun ray
 15 blocker devices are comprised of two sun blocker panels 111 and 112 and mounting, supporting, and deployment mechanisms by means of which the blocker panels are integrated with and deployed with the structures and mechanisms that support and cause the solar array to
 20 rotate. The radiators on the north and south panels 11 and 12 have dedicated sun ray blocker devices 111 and 112 attached to the north and south array assemblies 100 and 101, respectively, as shown in FIGURE 5. After the thus modified spacecraft 1 has been launched into the
 25 operational orbit and its appendages have been fully deployed, the sun blocker panels 111 and 112 will achieve their final positions in front of the cell side of the solar arrays with their surfaces more or less parallel to the plane of the solar arrays. The south blocker device
 30 112 is positioned such that during the time between the northern autumnal and northern spring equinoxes, when otherwise there would exist a potential for solar heating

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of the south panel 12, the south blocker device 112 will cast a shadow over the south panel 12 thereby eliminating the potential for such solar heating. The north blocker device 111 performs a similar function relative to the north panel 11 during the time between the northern spring and northern autumnal equinoxes. When the solar array assemblies 100 and 101 are maintained directly sun pointed, by virtue of their being rotated, the sun blocker devices will likewise be maintained directly sun pointed and thereby interposed between the Sun and the north and south panels that they shade.

The materials used for the sun blocker panels 111 and 112 are selected to minimize the heat transferred from their sun facing surfaces 111a and 112a to their anti-sunward surfaces 111b and 112b. This may be achieved by including insulating material(s) and constructions in the composition of the sun blocker panels. For example, the panels may include known thermally insulating materials and assemblies of materials, such as multi-layer insulation (MLI) blankets which utilize layered films of metallized Mylar separated by fabric netting. These materials and constructions are well known in the space industry and have typical heat resistance values of 0.007 to 0.01 Watt/deg.C/sq.in. The sun blocker panels of the present invention device will generally experience a sizable temperature difference, for example possibly greater than 100 degree C, between surface 111a and surface 111b and between surface 112a and surface 112b when the satellite is in its normal orientation in the mission orbit, except when the spacecraft is passing through the Earth's shadow.

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To obtain the maximum sun blocking effect, the panels of the sun ray blocker devices 111 and 112 are configured (sized, oriented, and positioned) in such a way that at the summer and winter solstices, when the Sun is about 23.5 degree from the orbit plane, the sun blocker devices will cast shadows that entirely cover the radiator surfaces on their respective thermal radiator surfaces on the spacecraft panels 11 and 12.

Accordingly, if the radiator surfaces are rectangular the shadows must be at least as wide as the diagonals of the rectangles.

FIGURES 6a, 6b and 6c show top partial views of a present invention arrangement as the spacecraft orbits Earth and the main body 10 is rotated at the orbital rate so that the earth panel 14 always faces Earth, and the sun blocker panels 111 and 112 always face the Sun (which is at the left in the FIGURES). These FIGURES are drawn in the inertial frame of reference of the solar array assemblies 100 and 101. Thus, if one were to stand on either of the solar array assemblies 101 and 102 one would see main body 10 rotate one revolution per orbital revolution around the Earth.

FIGURE 7 is a top partial section view showing more details of a present invention spacecraft. In this context the phrase "top view" denotes a view parallel to the planes of the sun blocker panels 111 and 112 and also parallel to the orbit plane. Note that in Figure 7 through Figure 15b various examples of embodiments of the present invention are depicted together with generic

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partial views of a spacecraft main body and a solar array assembly (labeled 400 and 408, respectively, later in FIGURES 10 and FIGURES 11). Additionally, FIGURES 8 and 9 show alternative embodiment arrangements in top partial section views.

In FIGURE 7, the spacecraft has main body 10, north panel 11, and solar cell panel support 223 with attached solar cell panel 225. In this case, there is a connecting solar array boom-and-yoke 219 and hinges at hinge points 221 and 227. Together this solar cell panel support 223, a solar cell panel 225, a solar array boom-and-yoke 219, and the hinges at hinge points 221 and 227 comprise part of a solar array assembly. The solar array boom-and-yoke 219 fold forwardly against north panel 11 and the solar cell panel support 223 together with the solar cell panel 225 folds down at hinge point 227 in an accordion-like fashion for launching. During launch, ascent, and orbit achievement the solar array assembly is in its folded-closed configuration. After achievement of the mission orbit it is electro-mechanically and/or mechanically deployed (unfolded) to allow the solar cells to be maintained directly sun-pointed. Attached to solar cell panel support 223 is a two-section connecting arm having a short inner portion 209 and an outer portion 207 connected by hinge(s) at hinge point 215. The anti-sunward side 111b of sun blocker panel 111 is connected to outer arm portion 207 by hinge(s) at hinge point 203. Optional solar cells 201 are functionally positioned on the sunward surface 111a of the sun blocker panel 111. Hinge points 203 and 215 provide for folding of the solar blocker panel 111 and its hinged arm 207 against the

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solar cell panel 225 in a compact and stiff configuration suitable for launch and subsequent deployment. The electromechanical and/or mechanical designs and methods for deploying (opening) and closing solar array assemblies are commonly used in contemporary spacecraft. The same or similar mechanisms are used to deploy the sun ray blocker devices of the present invention. These mechanisms and methods for deployment and closing are well within the skills of the artisan.

In FIGURE 7, there is an imaginary plane 250 extending off the surface of north panel 11. In its deployed configuration the sun blocker panel 111 may touch or extend through this imaginary surface, and consequently may provide additional shading for the earth, west, zenith and east panels as they rotate with respect to the Sun.

FIGURE 8 shows an alternative embodiment where sun ray blocker device 271 does not intersect imaginary plane 250. Further, it has a single connecting arm 205 with hinge points 203 and 217 at opposite ends to form an assembly and is connected directly to the substrate of solar cell panel 225. It may be folded and stowed for launch and deployed or unfolded in orbit in a similar way to the sun ray blocker device in FIGURE 7. In FIGURES 7 and 8, the sun ray blocker devices cast their shadows over the major part of the outer surface of north panel 11 and, in these embodiments, completely shadow that surface during the times when otherwise they would be exposed to the Sun. Further, the solar cells 201 may be

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included to produce additional solar power for the spacecraft.

5 In FIGURE 9, identical parts to FIGURES 7 and 8 are identically numbered. Sun ray blocker device 301 is connected directly to solar cell panel support 223 by hinge(s) at hinge point 309 so as to fold over up-close against solar cell panel 225 in the launch configuration. In this embodiment, sun ray blocker device 301 is not
10 parallel to the solar array, yet still effectively shades north panel 11.

FIGURES 10a, 10b and 10c depict a typical prior art sequence of deployment of a solar array assembly, which
15 is part of the transformation of the spacecraft from its launch configuration to its configuration for normal operations in orbit. For simplification in this document, only one (the north) solar array assembly is shown in the FIGURES. These particular FIGURES show a
20 satellite with a main body 400, and a solar array assembly 408 comprised of four solar cell panels, with solar cell surfaces 400a, mounted on solar cell panel supports 408 which are interconnected by hinges at three hinge points 403, 404, and 405 and connected to the main
25 body 400 by a single boom 419 and hinge(s) at hinge points 401 and 402. FIGURE 10a depicts the solar array assembly folded and stowed for launch. FIGURE 10b depicts it in the process of being deployed (unfolded). Figure 10c depicts its fully deployed state. If a
30 multiple-arm boom design is desired by the spacecraft designer, various embodiments can be designed to satisfy

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performance requirements using greater numbers of arms and hinge points.

FIGURES 11a, 11b and 11c illustrate the deployment sequence of one possible design embodying the present invention. Components in FIGURES 11a, 11b, and 11c that are identical to components in FIGURES 10a, 10b, and 10c are numbered identically to their identical parts. In addition to the prior art solar array assembly that was previously depicted in FIGURES 10a, 10b and 10c, FIGURES 11a, 11b, and 11c also depict the present invention sun blocker panel 411 connected to the solar array boom 419 by an arm 430 and hinges at hinge points 406 and 407. Alternatively, by design the sun blocker panel 411 could be hingedly attached via the arm 430 to a convenient different location on the solar array assembly. FIGURE 11a depicts the solar array assembly and the sun ray blocker device folded and stowed for launch, FIGURE 11b shows them partially deployed (unfolded). FIGURE 11c depicts their fully deployed state. FIGURES 12a and 12b show sun blocker panels which are not parallel to the plane containing the solar cell panels yet which still provide proper shading of the north or south panel. Components in FIGURES 12a and 12b and subsequent figures that are identical to components that appear in previous figures are numbered identically with their corresponding or very similar components or are left un-numbered to avoid unnecessary repetition. Alternatively, by design the sun blocker panel 111 could be hingedly attached via the arm 430 to a convenient different location on the solar array assembly.

FIGURE 13 depicts yet another alternative embodiment of the present invention. The sun blocker panel 511 is connected to the solar array boom 219 by hinge(s) at hinge point 507 for its stowing folded and subsequent deployment.

FIGURES 14a and b show an arrangement similar to that in FIGURE 13, with identical parts identically numbered, however, more hinges at hinge points 606 and 607 are used with blocker panel 611 as required by design for folding the panels prior to deployment.

FIGURE 14b represents a partial view of the anti-sun side of the spacecraft looking toward the Sun (i.e. a side view relative to the top view shown in Figure 14a).

FIGURES 15a and 15b show one embodiment in which sun blocker panel 811 utilizes separate active motors 306 and 307 which are used to actively deploy and/or retract the sun ray blocker device. This arrangement allows satellite operators to use deployment motors that are separate from the solar panel deployment motors so as to permit them to retract the sun blocker panels to prevent their interference, if any, in satellite operations such as in the use of propulsion systems during spacecraft performance of station keeping or attitude control maneuvers.

In some spacecraft designs the required size (dimensions and/or area) of a sun blocker panel in its fully deployed configuration may exceed the constraints of its "launch envelope" i.e. the constraints of the

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maximum-allowable space allocated to the sun ray blocker device in the launch configuration of the spacecraft when the solar array and the sun ray blocker device are in their launch configuration. Therefore, for compatibility
5 with the constraints of the size of the corresponding launch envelope it may be necessary for the sun blocker panel of the sun ray blocker device to be comprised of several (i.e. more than one) pieces, instead of being one single integral piece, which are folded together in the
10 launch configuration and are subsequently deployed (unfolded) in orbit to form effectively one continuous sun blocker panel. FIGURES 16a, 16b and 16c, and FIGURES 17a, 17b and 17c, respectively depict two examples from the many possible designs for sun blocker panels which
15 fold and deploy. Parts a, b, and c of the FIGURES 16 and 17 show each of the two designs in a view from the front (Sun) direction with the sun blocker panel fully deployed, and two views from a direction orthogonal to both the front view and the top view directions with the
20 sun blocker panel folded and deployed, respectively. (As defined earlier herein the phrase "top view" denotes a view that is simultaneously parallel to the plane of the sun blocker panels 921 or 951 and the orbit plane.) This allows the sun ray blocker device to increase its
25 dimensions using hinge(s) and/or strut(s) and/or flap(s) etc. at hinge points 925 and 927 or a slide-out design. Referring collectively to all FIGURES 16, sun blocker panel 921 has a center section 923 with hinge(s) and/or strut(s) and/or flap(s) etc. at hinge points 925 and 927
30 and outer, swing up panels 929 and 931 which may be designed to deploy (swing up) automatically. In all FIGURES 17, sun blocker panel 951 has main section 953

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with slide-out extensions 955 and 957 that may be designed to deploy (slide out) automatically. (Automatic hinging and automatic sliding or telescoping is well within the purview of the artisan in the spacecraft industry and need not be further elaborated upon herein.)

The embodiments of the present invention device illustrated in FIGURES 18 through FIGURE 30 are as generally applicable as the other embodiments described herein. However, they also function efficiently in cases where a sun blocker device cannot be attached to an axle located near the center (1811, 2123, 2722) of an associated thermal radiator surface (1804, 2121, 2721).

One such case is that in which the axis of rotation (1803, 2131, 2701) of a solar array assembly extends outward from the associated thermal radiator surface (1804, 2121, 2721) at a location that is significantly offset from the center (1811, 2123, 2722) of the thermal radiator surface. In that case, designs with an attachment arm of fixed length between the sun blocker panel and the solar array axis could be unsuitable, because the motion of the sun blocker panel about the center of the thermal radiator surface would be eccentric.

Another such case is that in which there are stay-out zones inboard of the periphery of the associated thermal radiator surface - through which objects such as a supporting boom (for example for a sun blocker panel) are not allowed to pass. This could be the case, for example, when certain attitude- or orbit- control

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thrusters (1810) are also located on the panel upon which the thermal radiator surface (1804) is located.

5 The arrangements illustrated in FIGURES 18 through
FIGURE 30 may be employed to overcome these constraints,
whilst still maintaining a sun blocker panel at a
substantially uniform distance from the center of the
associated thermal radiator surface. Selection between
10 the embodiments shown in FIGURES 18-30 for any particular
application may involve trade-offs between many
additional performance-requirements of the spacecraft-
system, including for example: mass, strength, stiffness,
flatness, circularity, simplicity, and reliability.

15 Figure 18 shows an embodiment of a sun blocker
device in which the sun blocker panel 1800 is mounted on
a carriage 1801 with wheel-sets or bearing-sets 1808 and
1830 by means of an attachment arm 1805 in which the
carriage may be driven around a closed rail 1802, the
20 carriage 1801 being attached to the rail 1802 by rolling
or sliding means that also react against and thereby
limit rotations of the carriage 1801 (and thereby the sun
blocker panel) about axes passing through the points of
contact of the carriage and the rail. In one of many
25 potential embodiments, for example, this may be achieved
using wheel or bearing sets 1808, 1830 that are
adequately spaced both along-track and cross-track on
both sides of the rail 1802, and which are also cambered
at an adequate angle to the plane of the baseplate.
30 Attached to the carriage is at least one generally-radial
boom or strut 1805, an outer end of which is attached to
the sun blocker panel at hinge point 1812 and an inner

end of which is attached to the carriage 1801 at hinge-
 point 1813, and the carriage is rollingly or slidingly
 mounted on the rail 1802 by the wheels or bearings 1808
 and 1830. At least one of these wheels 1830 or bearings
 5 is provided with a motor to drive the carriage along the
 rail 1802, for example by friction, or by the engagement
 of a toothed wheel or a worm-drive in a rack. Electrical
 power may be supplied to the motor, via brushes for
 example. The attachment arm 1805 and the sun blocker
 10 panel 1800 can be folded at the hinge points 1812 and
 1813 to achieve a stowed configuration of the sun blocker
 device for launch, during which the folded device may be
 temporarily caged securely for proper management of
 launch-induced dynamic environments and loads. The sun
 15 blocker panel may be further folded for launch as
 illustrated in FIGURES 16 and 17. Following launch the
 attachment arm 1805 and the sun blocker panel 1800 can be
 deployed for subsequent operation in orbit, including
 sun-tracking travel around rail 1802. It will be
 20 appreciated that the rail 1802 need not be circular as
 shown in FIGURE 18, but in the case of a significantly
 rectangular thermal radiator surface, for example, the
 rail could be elliptical and in either case may be
 diverted to avoid obstacles mounted on the spacecraft.

25 Alternatively, as illustrated in FIGURE 19 the
 attachment arm 1805 could be mounted on a solid rotatable
 wheel instead of on a carriage and rail. In the
 embodiment illustrated in FIGURE 19 the wheel is a ring
 30 or annulus 1902 floating in circumferentially located
 bearing-sets 1903 and controlled and driven by a motor
 1930 mounted on the baseplate under 1804.

In a similar alternative embodiment, illustrated in FIGURE 20, a carriage 2001, similar to that provided in the embodiment illustrated in FIGURE 18, is provided; but in this embodiment the carriage 2001 is driven around a closed rail 2002 not by a motorized wheel, but by an endless belt 2003, chain, or cable attached to the carriage 2001, the belt being driven by a motor 2030 that is mounted to the baseplate under 1804 and which engages the belt 2003, chain, or cord. A tensioning device 2040 is also provided to engage the belt 2003 and tension the belt while not impeding the passage of the carriage around the rail 2002. Again, as in the embodiment illustrated in FIGURE 18 the rail 2002 need not be circular.

Figures 21 through 30 illustrate embodiments in which a sun blocker panel is mounted on the spacecraft via an attachment arm from an axis 2131, 2701 that is offset from the center 2123, 2722 of an associated thermal radiator surface. The axis 2131, 2701 could be concentric with or identical to the axis of rotation of a solar array assembly.

Figures 21 through 26 illustrate an alternative embodiment in which a sun blocker panel 2100 is attached to an axle at axis 2131. The axle may be either concentric with or identical to an axle of a solar array assembly. The sun blocker panel is attached to the axle by an articulated attachment arm 2130 that included three articulated portions 2132, 2134, 2137.

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The inner end of the inner-portion 2132 is fixed radially to the axle at axis 2131. The middle-portion 2134 is pivoted at its inner end to inner-portion 2132 at pivot-point 2133, and the outer end of middle-portion 2134 is pivoted to the inner end of outer-portion 2137 at pivot point 2135. At its outer end the outer-portion is attached to the sun blocker panel at hinge point 2138 and near its inner end the outer-portion is hinged at hinge point 2136 to allow folding and stowing for launch followed by deployment in orbit.

As depicted in FIGURE 21 through FIGURE 26 the inner-portion 2132 and the outer portion 2137 of the attachment arm 2130 turn anti-clockwise at the same rate, the outer-portion 2137 carrying the sun blocker panel with it, whereas the middle portion 2134 rotates clockwise at the same rate.

The length of the inner-portion 2132 is approximately equal to the offset of the axis of rotation 2131 from the center 2123 of the thermal radiator surface. In principle the length of the middle-portion 2134 may be longer or shorter than the length of the inner portion 2132. However, in the case that the axis of rotation 2131 is occupied by an obstruction such as the axle of a solar array assembly then the middle-portion 2134 must be shorter than the inner-portion 2132 for clearance of the solar array axle at axis 2131, as can be seen in FIGURE 23 in which the attachment arm 2130 is approaching its closest to the axle at axis 2131.

By articulating the articulated portions through rotation of the arm 2130 about the axis of rotation 2131 the sun blocker panel can be maintained at a substantially constant distance from the center of the associated thermal radiator surface 2121, to describe a substantially circular path 2140 around the spacecraft. It will be evident that in the case of a thermal radiator surface that is significantly far from being radially symmetric the length of the articulated portions of arm 2130 could be adapted to achieve a wide range of desired paths around the thermal radiator surface.

As shown in FIGURE 21, the articulated portions 2132, 2134, 2137 are arranged to the full reach of attachment arm 2130 in a straight line when the sun blocker panel is passing a side of the thermal radiator surface furthest from the axis of rotation 2131. As shown in FIGURES 22 and 23 the attachment arm 2130 has an effective length equal to the sum of the lengths of an outer 2137 and an inner 2132 articulated portion when the sun blocker panel 2100 is at an intermediate distance from the axis of rotation 2131. As shown in FIGURE 23, the effective length of the attachment arm 2130 is at its minimum when the sun blocker panel is at its closest to the axis of rotation 2131, at which point its length is equal to the sum of the lengths of the inner 2132 and outer 2137 portions less twice the length of the middle-portion.

The inner articulated portion 2132 of the attachment arm 2130 rotates about axis 2131. The means of attachment of the inner articulated portion 2132 may be

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independent of a solar array axle along axis 2131, the inner portion 2132 then being mounted to a concentric tubular axis around a central solar array axle. Alternatively, the inner articulated portion may be fixed solidly to a solar array axle along axis 2131.

In the illustrated embodiment, for a geostationary spacecraft for example the inner and outer articulated portions rotate anti-clockwise at one revolution per day, and the middle articulated portion rotates clockwise at one revolution per day. This rotational relationship may be achieved by diverse means, such as: separate motorized pivots at pivot points 2131, 2133, and 2135; or by a system of belt-linked pulley wheels at pivot points 2131, 2133 and 2135, driven by a single motor or by an axle along axis 2131.

The articulated portions 2132, 2134, and 2137 may be sprung together, so that in a failure mode the attachment arm 2130 automatically extends to its greatest length. In that case, any failed pivot points can be made to fail free, for example using commandable frangible-links in the associated pulley wheels or drive motor, allowing spring-driven extension of the arm 2130.

FIGURES 25 and 26 illustrate a means of articulating the articulated portions 2132, 2134, 2137 with respect to each other, utilizing a driving force from a solar array axle at axis of rotation 2131. A cylinder 2501 is provided, mounted co-axial with the solar array axle at axis 2131 but fixed to a base panel 2121. The inner articulated member 2132 is fixed to the solar array boom

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at axis 2131 so that the inner articulated member 2132 rotates at the same rate as the solar array boom at axis 2131. A middle articulated portion 2134 is pivotally fixed to an outer end of the inner articulated portion 2132 at a pivot point 2133 and a pulley wheel 2502 of the same diameter as cylinder 2501 is fixed to an inner end of the middle articulated portion 2134. A toothed belt 2506 is looped around the cylinder 2501 and the pulley wheel 2502 so that as the solar array shaft 2131 and the inner articulated portion 2132 rotate anti-clockwise in a direction of the arrow 2507, the toothed belt 2506 causes the pulley wheel 2502 and the middle articulated portion 2134 to counter-rotate at the same rate in the direction of arrow 2508.

15

As shown in FIGURE 26, a second equal sized pulley wheel 2601 is fixed to an outer end of the inner articulated portion 2132 on a side of the inner articulated portion 2132 opposite to that on which the cylinder 2501 is fixed to base panel 2121, and a third equal sized pulley wheel 2602 is fixed to an inner end of an outer articulated portion, such that the third pulley wheel 2602 and the outer articulated portion 2137 are together pivotally attached to the outer end of the middle articulated portion 2134. A second toothed belt 2603 loops around the second pulley wheel 2601 and the third pulley wheel 2602 so that as the middle articulated portion 2134 rotates in the direction of arrow 2508 the toothed belt 2603 causes the outer articulated portion 2137 and the third pulley wheel 2602 to counter-rotate at the same rate in the direction of arrow 2604. Thus, the outer articulated portion 2137 rotates in the same sense

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as the inner articulated portion 2132 whereas the middle articulated portion 2134 counter-rotates.

In a further embodiment illustrated in FIGURES 27
5 through 30, a sun blocker panel 2700 is attached to an
axle 2701 of a solar cell array by means of a scissor
attachment arm 2730. The scissor arm is comprised of a
first articulated arm 2704, 2708 and a second articulated
arm 2705, 2709, comprised of inner articulated portions
10 2704, 2705 and outer articulated portions 2708, 2709
respectively. The inner articulated portions are
connected by hinges at hinge points 2702, 2703 to the
solar array boom 2701 respectively and the outer ends of
the outer articulated portions 2708, 2709 are connected
15 by hinges 2710, 2711 to the sun blocker panel 2700 such
that when the articulated arms are extended to the full
length they are still not parallel to avoid their locking
up. A lanyard 2712 is located in between the articulated
arms 2704, 2708 and 2705, 2709 and extends between the
20 sun blocker panel 2700 and the solar array axle 2701.
The inner articulated portions 2704, 2705 and the outer
articulated portions 2708, 2709 are sprung at hinge
points 2706 and 2707 so as to automatically extend the
articulated arms 2704, 2708 and 2705, 2709 to their full
25 extent as limited by the lanyard control. The
articulated arms 2704, 2708 and 2705, 2709 thereby form a
parallelogram, the shape of which may be controlled by
retracting or deploying the lanyard 2712. Alternatively
the shape of the parallelogram could be controlled by
30 motorized hinges, or alternatively by a retractable and
deployable lanyard between hinge points 2706 and 2707
with sprung hinges 2702, 2703, 2710 and 2711 instead of

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at 2706 and 2707. In the embodiment of the invention illustrated in FIGURES 21 through 24, the distance of the sun blocker panel 2700 from the solar array boom 2701 can be varied as the sun blocker panel 2700 rotates about the solar array boom 2701 to maintain the sun blocker panel at a constant distance from the spacecraft as illustrated by the path 2712.

The embodiments described in FIGURES 18 through 20 have the advantage that the attachment arm does not obscure thrusters 1810 present on the face of the spacecraft, that the sun blocker panel shades.

A sun blocker panel 3100, 3200 is not necessarily rectangular in shape. As shown in FIGURE 31, the sun blocker panel 3100 has trapezoidal first-and second-extensions 3101, 3102 hingedly attached to a main body 3103 of a sun blocker panel 3100. The first extension 3101 is extended by unfolding the extension through rotation in the direction of the arrows 3104 and the second extension is extended by unfolding the extension through rotation in the direction of the arrows 3105 from a position flat against the main body 3103.

As shown in FIGURE 32 a rectangular main body 3202 of the sun blocker panel 3200 may have substantially triangular extensions 3201, 3202 which may be extended and retracted from the main body by sliding translation of the extension 3201 in the direction of double-handed arrow 3204 and unfolding the extension 3202 in the direction of arrows 3205.

The descriptions of designs for the structural support and the deployment of sun ray blocker devices written herein are examples from thousands of possible structural support and deployment designs which can be used for this purpose and are within the scope of the present invention.

This paragraph describes an example to demonstrate the geometrical approach to calculating the dimensions of a sun blocker panel for providing total shadow coverage to a quasi-rectangular shaped radiator surface. The example used is that of a radiator surface on a north or south panel of a geostationary spacecraft, like the previously defined "model" spacecraft for example, at the summer or winter solstice, when the incidence angle of the Sun's rays (measured from the plane of the benefited thermal radiator surface) is at a maximum, using a quasi-rectangular (for this simple illustration at least) shaped sun blocker panel whose plane is perpendicular to the plane of the associated thermal radiator surface (referring to FIGURE 12a, angle θ is then 90 degree). For this example, take the north or south radiator-surface of the spacecraft to be rectangular, of length and width A and B, respectively. Then, the length and width dimensions, L and W, respectively, of the sun-exposed surface of the fully-deployed sun blocker panel (which is shown in FIGURES 16a and 17a) should be as follows: L is greater than or equal to $\sqrt{A^2+B^2}$, and W is greater than or equal to $0.435 \times \sqrt{A^2+B^2}$ based on the corresponding orbit-sun angle of 23.5 degree. However, if only a portion of the surface area on the north or south panel needs to be shadowed, i.e. high heat-dissipating

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equipments were to be mounted in certain localized areas of the north or south panel, the sun ray blocker device can be tailored to shade only those areas and may accordingly be smaller. In addition, if a sun blocker panel whose plane is not perpendicular to the plane of the associated thermal radiator surface were to be selected by the spacecraft designer, the minimum value of the width, W , may be greater or less than $0.435 \times \sqrt{(A^2+B^2)}$ depending on the size of angle 501 in FIGURE 12a. If angle 501 is greater than 90 degree, W may be greater than $0.435 \times \sqrt{(A^2+B^2)}$; if it is less than 90 degree, W may be less than $0.435 \times \sqrt{(A^2+B^2)}$. If additional shading to the other four panels, earth, zenith, east and west panels, is desired, the width (W) of the sun blocker panel can be increased to extend past the imaginary plane 250 toward the center of the satellite as shown in FIGURE 7.

Thus, by the foregoing descriptions contained herein it can be seen that by virtue of the present invention losses in the efficiency of the cooling of the thermal radiator panels of a spacecraft caused by solar heating can be eliminated or minimized via various sun blocking arrangements.

25

Obviously, numerous modifications to and variations on the present invention are possible in light of the above teachings. For example, as a practical matter, a designer might counterweight or counterbalance the rotating axles or arms to overcome the weight imbalance caused by sun ray blocker devices of the present invention without exceeding the scope of the present

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invention. It is therefore understood that within the scope of the appended claims, the invention may be practiced otherwise than as specifically described herein.

5

CLAIMS

1. A spacecraft for orbiting a sunlit celestial body (300), the spacecraft including a thermal radiator surface (11,12,1804, 2121, 2721) for radiating heat
5 from the spacecraft into space, and a sun ray blocker device (111,112, 141, 271, 301, 411, 511, 611, 811, 921, 951,1800,2100, 2700) mounted on said spacecraft for shielding said thermal radiator surface (11,12,1804,2121,2721) from rays of sunlight,
10 characterised in that said sun ray blocker device is locatable for placing in shadow substantially the whole of the thermal radiator surface (11,12,1804,2121,2721) from sunlight without substantially impeding thermal radiation from said thermal radiator surface
15 (11,12,1804,2121,2721) into space.
2. A spacecraft as claimed in claim 1, wherein an effective radiation view factor for thermal radiation from the thermal radiator surface (11,12,1804, 2121,2721) to deep space is significantly greater than
20 corresponding geometrical radiation view factor to deep space, and in particular, for a geostationary spacecraft where the geometrical radiation view factor to deep space is 0.65, the effective radiation view factor to deep space is at least 0.87.
- 25 3. A spacecraft as claimed in claims 1 or 2, wherein the sun ray blocker device includes at least one sun blocker panel (111, 112) having a sun-facing surface (111a, 112a) and an opposed anti-sun-facing surface (111b, 112b), wherein the sun-facing surface (111a,

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112a) is thermally insulated from the opposed surface (111b, 112b).

4. A spacecraft as claimed in claim 3, wherein the sun-facing surface (111a, 112a) is thermally insulated from the opposed surface (111b, 112b) by a multi-layer insulation blanket.
5. A spacecraft as claimed in claims 3 or 4, wherein the sun-facing surface (111a, 112a) has a low solar energy absorptivity of less than 0.5.
- 10 6. A spacecraft as claimed in any of claims 3 to 5, wherein the sun-facing surface (111a, 112a) includes a solar cell panel for supplying electrical power to the spacecraft.
- 15 7. A spacecraft as claimed in any of claims 3 to 6, wherein the sun-facing surface (111a, 112a) has a high thermal emissivity of higher than 0.7.
- 20 8. A spacecraft as claimed in any of claims 3 to 7, wherein the sun ray blocker device (111, 112, 141, 271, 301, 411, 511, 611, 811, 921, 951, 1800, 2100, 2700) is moveable between a stowed, non-operative position and a deployed operative position.
- 25 9. A spacecraft as claimed in any claims 3 to 8, wherein the sun ray blocker device (111, 112, 141, 271, 301, 411, 511, 611, 811, 921, 951, 1800, 2100, 2700) includes an attachment arm (207, 205, 430, 230) for attaching the sun blocker panel (111, 112) to the spacecraft.

10. A spacecraft as claimed in claim 9, wherein the attachment arm (207, 205, 430, 230) is attached by a hinge means (406, 306) to the sun blocker panel (111, 112) and/or by a second hinge means (407, 507, 607, 307) to the spacecraft.

11. A spacecraft as claimed in any of claims 8 to 10, wherein the sun ray blocker device (111, 112; 141; 271; 301; 411; 511; 611; 811; 921; 951) includes a motor for moving the sun ray blocker device (111, 112; 141; 271; 301; 411; 511; 611; 811; 921; 951) between the stowed position and the deployed position.

12. A spacecraft as claimed in any of claims 3 to 11, wherein locating means are provided for locating the sun ray blocker device (111, 112; 141; 271; 301; 411; 511; 611; 811; 921; 951) with respect to the thermal radiator surface (11, 12) which includes adjustment means to maintain the majority of the thermal radiator surface (11, 12) in shadow irrespective of changes in the attitude and/or orbit of the spacecraft during normal operations.

13. A spacecraft as claimed in claim 12, wherein the adjustment means includes a variable length attachment arm (2130, 2730) for attachment of the sun blocker panel to the spacecraft.

14. A spacecraft as claimed in claim 13, wherein the attachment arm is a scissor arm (2730).

15. A spacecraft as claimed in claim 13, wherein the attachment arm (2130) is formed of articulated portions (2132, 2134, 2137) which may be mutually articulated.

15. A spacecraft as claimed in claim 13, wherein the transport means includes rail means (2002) and belt means (2003) connected to the carriage means (2001), the belt means being driven by drive means (2030) to move the carriage means along the rail means (2002).
5
16. A spacecraft as claimed in claim 13, wherein the carriage means includes an annulus (1920) rotatable in a circular path defined by bearing means (1903) the annulus being driveable by drive means (1930) to move the carriage along the path defined by the bearing means.
10
17. A spacecraft as claimed in any of claims 12 to 16, having a solar cell array (100, 101, 408) adapted for tracking movements of the Sun relative to the spacecraft, wherein the adjustment of the location of the sun ray blocker device (111, 112, 141, 271, 301, 411, 511, 611, 811, 921, 951) in relation to the thermal radiator surface (11, 12, 1804, 2121, 2721) is synchronised with the tracking movement of the solar cell array, when in normal operation.
15
20
18. A spacecraft as claimed in claim 17, wherein the sun ray blocker device (111, 112; 141; 271; 301; 411; 511; 611; 811; 921; 951) is mounted on the solar cell array (100, 101 408) or on means carrying said solar cell array.
25
19. A spacecraft as claimed in claim 18, wherein the solar cell array tracks the movement of the Sun by rotation of the solar cell array about an axis of rotation of the solar cell array (100, 101, 408) such

that the sun blocker panel (111, 112) also rotates about said axis of rotation of the solar cell array.

20. A spacecraft as claimed in claim 19, wherein the thermal radiator surface (11,12) is orthogonal to the axis of rotation of the solar cell array so that the sun blocker panel (111, 112) rotates about an axis normal to the thermal radiator surface.

21. A spacecraft as claimed in claim 18-20, wherein the adjustment means includes a variable length attachment arm (2130, 2730) for attachment of the sun blocker panel to the spacecraft.

22. A spacecraft as claimed in claim 21, wherein the attachment arm is a scissor arm (2730).

23. A spacecraft as claimed in claim 21, wherein the attachment arm (2130) is formed of articulated portions (2132, 2134, 2137) which may be mutually articulated during rotation to vary an effective length of the attachment arm.

24. A spacecraft as claimed in any of claims 21-23, wherein the adjustment means for attachment of the sun blocker panel (2100, 2700) to a solar cell array assembly (2131, 2701) are such that a distance between the sun blocker panel from the solar cell array assembly (2130, 2730) may be varied during rotation of the sun blocker panel.

25. A spacecraft as claimed in any of claims 3 to 24, wherein means (929, 931, 955, 957) are provided for adjusting the size of the sun blocker panel (111, 112).

26. A spacecraft as claimed in any of the preceding claims, including control means for controlling the spacecraft so as to maintain an angle between a sun line and the thermal radiator surface (11,12) below a predetermined angle by adjustment of the orbit and/or attitude of the spacecraft in use.

27. A spacecraft as claimed in claim 26, wherein the predetermined angle is 60 degrees.

28. A spacecraft as claimed in claims 26 or 27, wherein the control means is adapted to maintain the thermal radiator surface (11,12) substantially parallel to a plane of an orbit of the spacecraft.

29. A spacecraft as claimed in any of claims 26 to 28, wherein the control means is adapted to maintain the spacecraft in a sun synchronous orbit.

30. A spacecraft as claimed in any of claims 26 to 28, wherein the control means is adapted to maintain the spacecraft in an equatorial or low-inclination orbit.

31. In a three axis stabilised spacecraft for orbiting about a planet and having at least one solar cell assembly having at least one solar cell panel, and being a north solar cell panel assembly or a south solar cell panel assembly, said at least one solar cell panel assembly being mounted on an axle so as to be controllably rotated from said spacecraft about an axis of rotation so as to face the Sun, said spacecraft having a nadir panel which is generally pointing to the centre of the planet, an opposite panel known as a zenith panel, which faces away from the centre of the

planet and sharing the same planar normal vector as said nadir panel, an east panel and a west panel, said east panel and said west panel having their planar normal vector laying on a orbital plane pointing to the velocity vector of the spacecraft generally tangential to the direction of travel on the orbit, and a north panel and a south panel, said north panel and said south panel having their planar normal vector generally perpendicular to the orbit plane and parallel to the axis of rotation of the planet, said solar cell panel extending outwardly from said spacecraft, the improvement which comprises:

attaching at least one sun ray blocker device to said at least one solar cell panel, said at least one device being either a north blocker device or being a south blocker device and corresponding to said at least one solar cell panel, each of said at least one sun ray blocker device being positioned forwardly from and offset relative to a solar cell surface of a solar cell panel and at a predetermined angle to either of said north panel and said south panel, said north panel or said south panel, said sun ray blocker device being positioned so as to cast a shadow on at least a majority of the exposed surface of its corresponding north or south panel during solar exposure thereto.

32. In a three axis stabilised low inclination orbit spacecraft for orbiting about the earth and having two sets of solar cell array assemblies having solar cell arrays, one set being a north solar array assembly and the other being a south solar array assembly, said assemblies each being mounted on an axle so as to be

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controllably rotated from said spacecraft about an axis of rotation so as to face the Sun, said spacecraft having an earth panel which is generally pointing to the centre of the earth, an opposite panel known as a zenith panel, which faces away from the centre of the earth and sharing the same planar normal vector as said earth panel, an east panel and a west panel, said east panel and said west panel having their planar normal vector laying on an orbital plane pointing to the velocity vector of the spacecraft generally tangential to the direction of travel on the orbit, and a north panel and a south panel, said north panel and said south panel having their planar normal vector generally perpendicular to the orbit plane and parallel to the axis of rotation of the earth, said solar cell panel extending outwardly from said spacecraft, the improvement which comprises:

attaching at least one sun ray blocker device to each of said north solar array and said south solar array, one device being a north device and another device being a south device, each of said sun ray blocker devices being in the form of a panel and being positioned forwardly and offset relative to the solar cell surface of a solar ray and at a predetermined angle to said north panel and said south panel, said north blocker device being positioned so as to cast a shadow on at least a majority of the exposed surface of said north panel during solar exposure thereto, and said south blocker device being positioned so as to cast a shadow on the exposed surface of said south panel during solar exposure thereto.

ABSTRACT

SPACECRAFT

5 A spacecraft having a sun ray blocker device (111, 112, 141, 271, 301, 411, 511, 611, 811, 921, 951, 1800, 2100, 2700) for shading a thermal radiator surface (11,12) of the spacecraft in which the sun ray blocker device is movable in relation to the thermal radiator
10 surface to keep the surface substantially in shade without substantially blocking thermal radiation from the thermal radiator surface to deep space. Preferably a sun-facing side (111a, 112a) of the sun ray blocker device is thermally insulated from an opposed side (111b, 112b)
15 to reduce thermal radiation from the sun ray blocker device to the thermal radiator surface and the sun ray blocker device is also preferably deployable in orbit after launch.

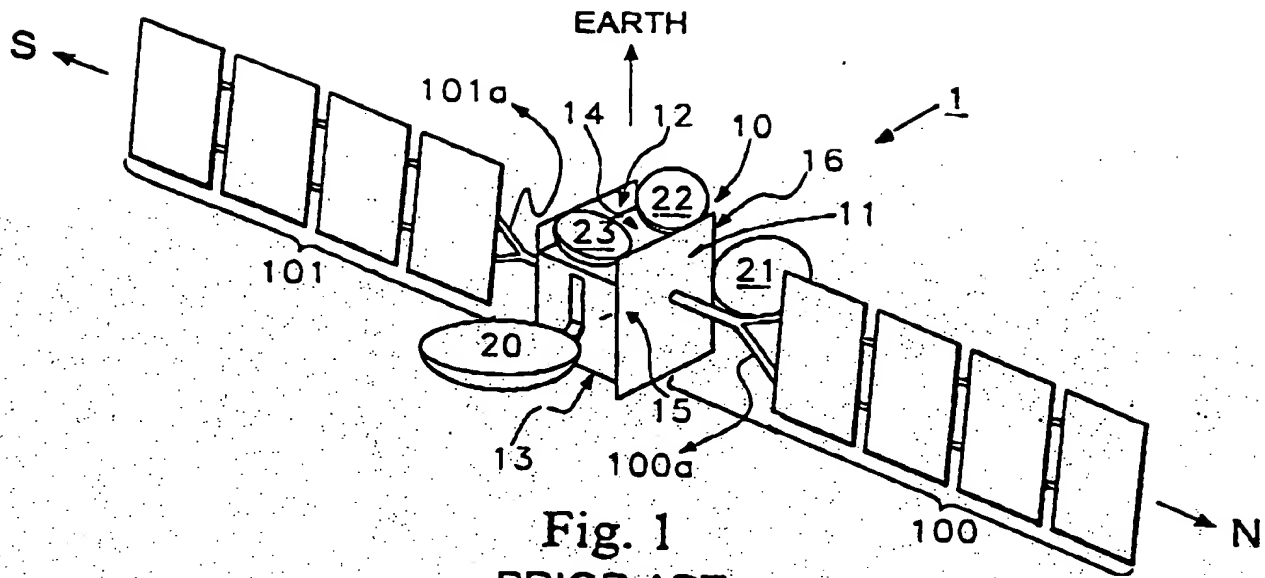


Fig. 1
PRIOR ART

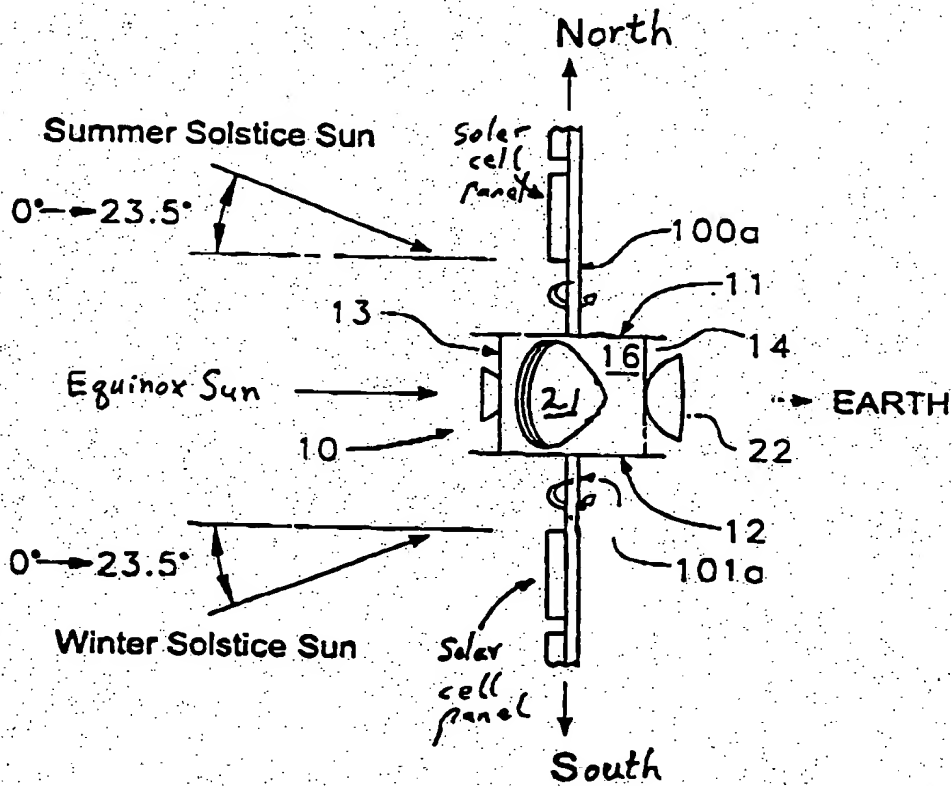


Fig. 2
PRIOR ART

2/19

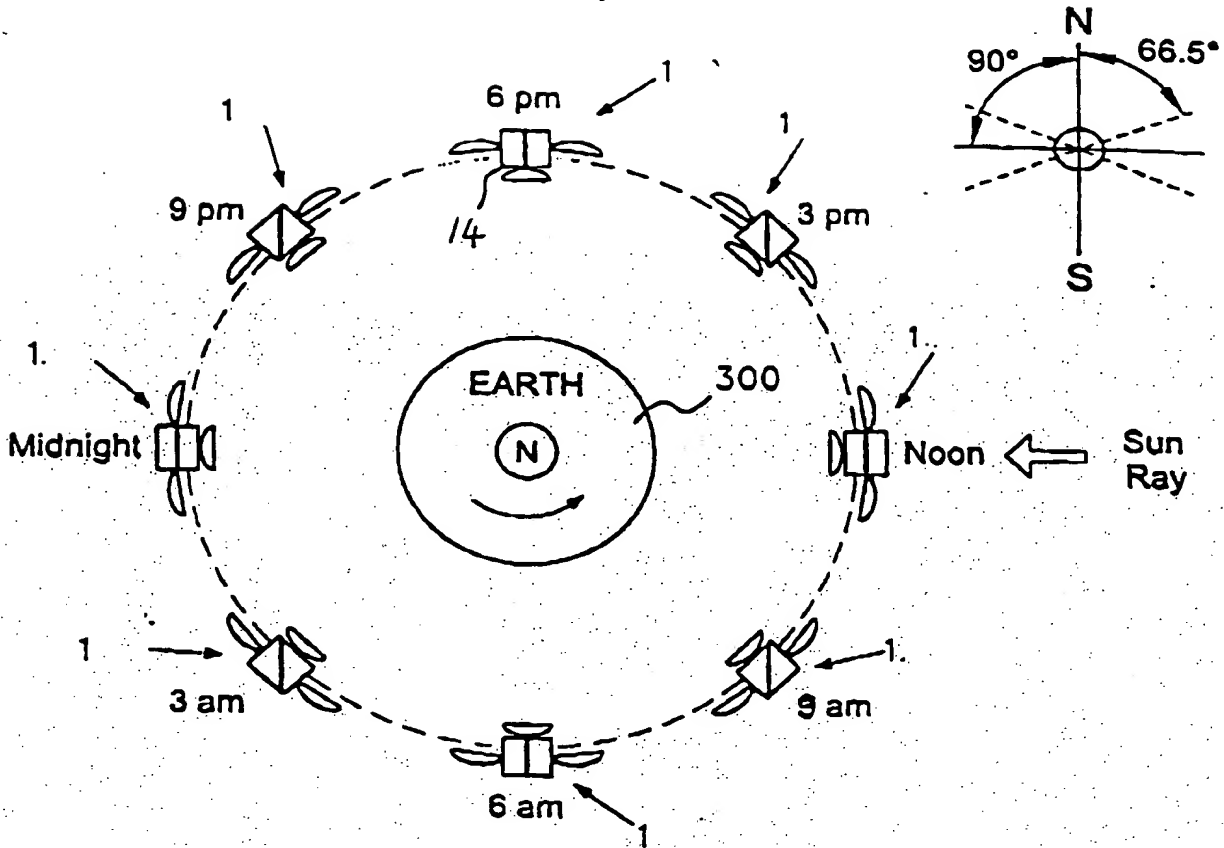


Fig. 3a
PRIOR ART

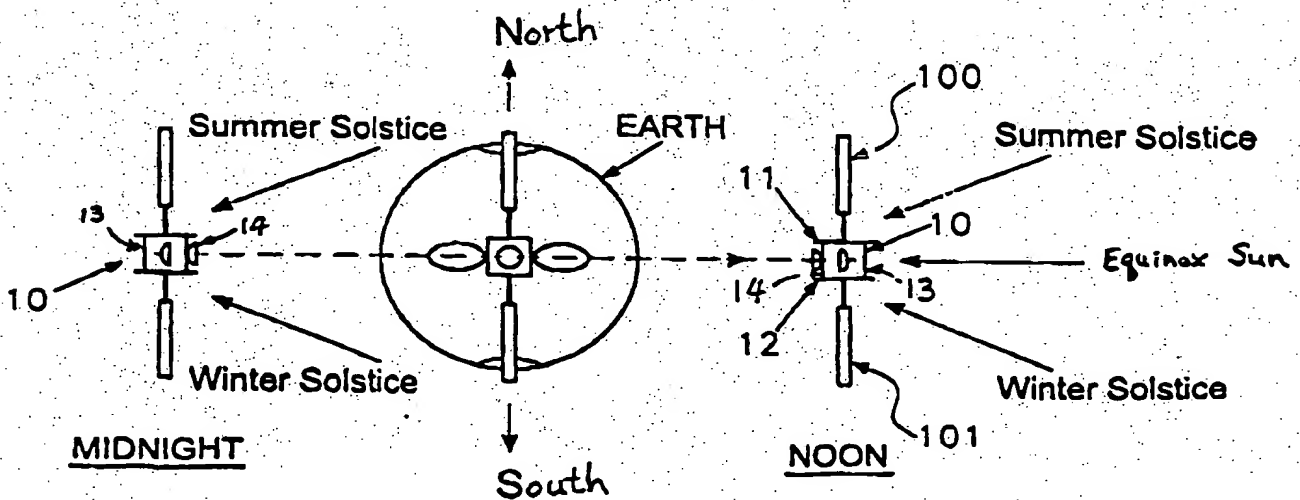


Fig. 3b
PRIOR ART

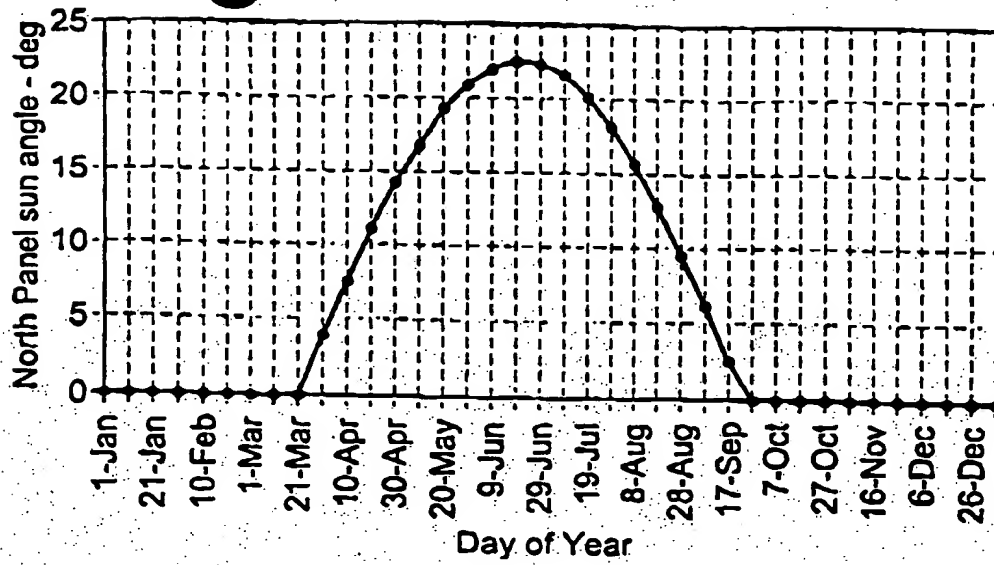


Fig. 4a

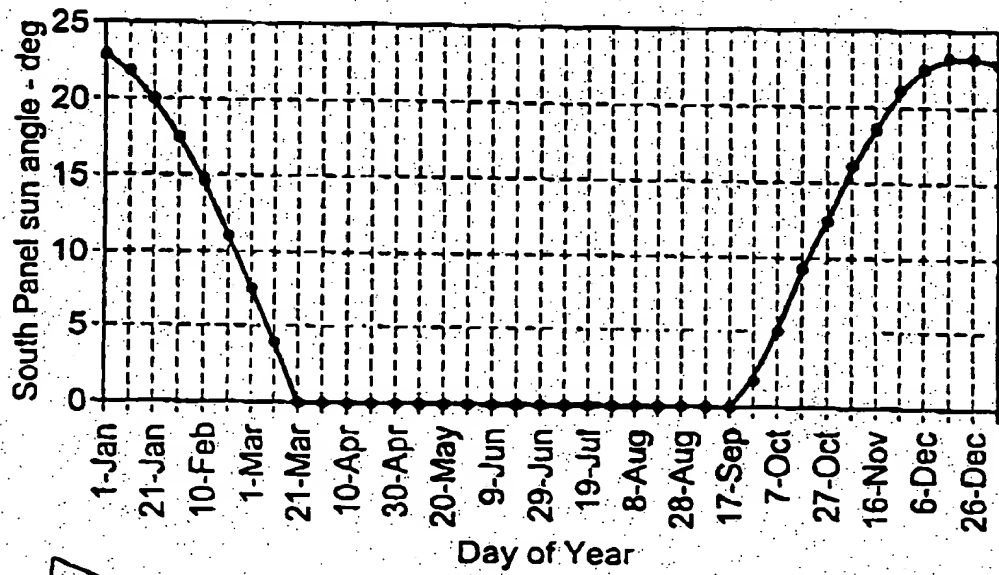


Fig. 4b

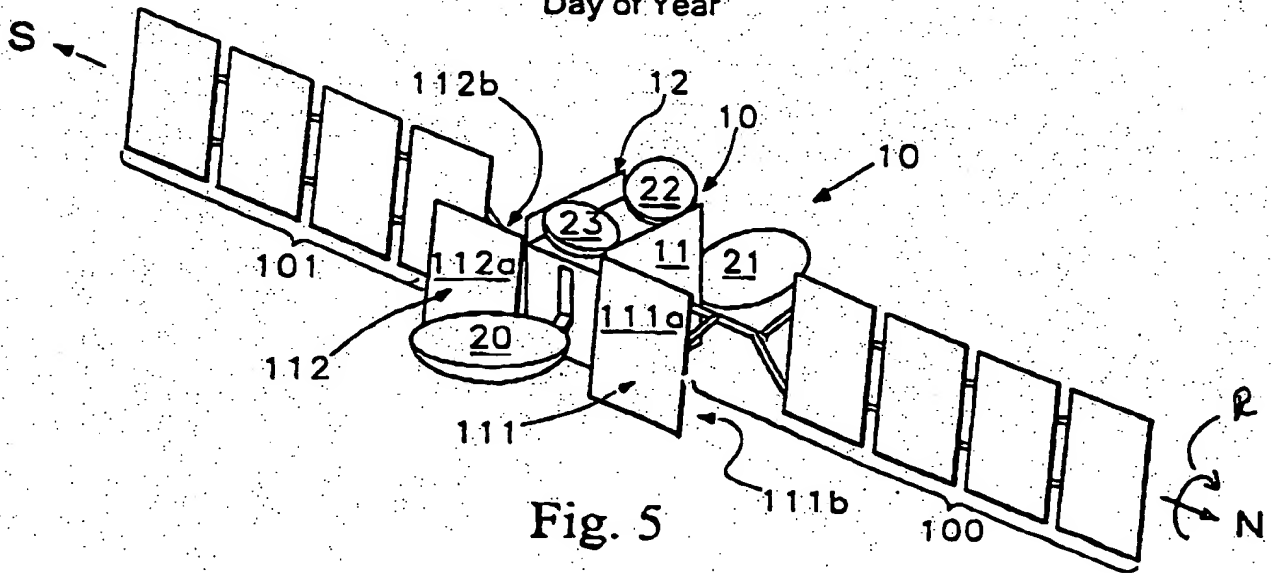


Fig. 5

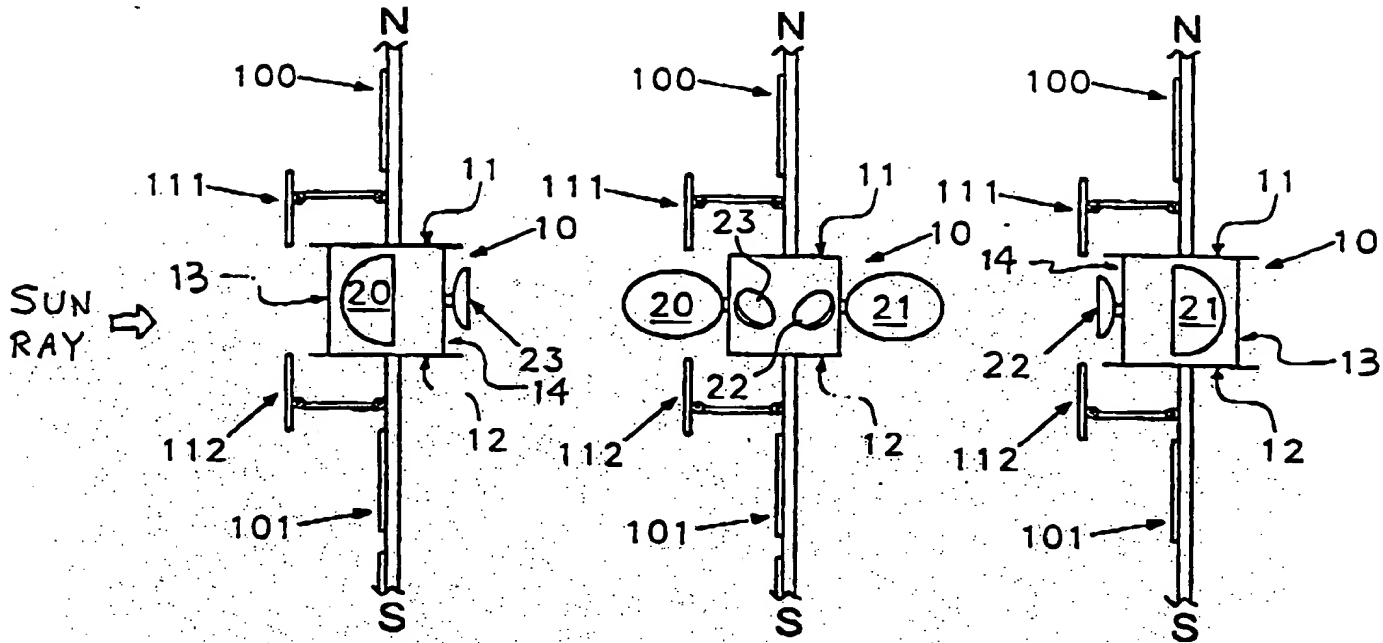


Fig. 6a

Fig. 6b

Fig. 6c

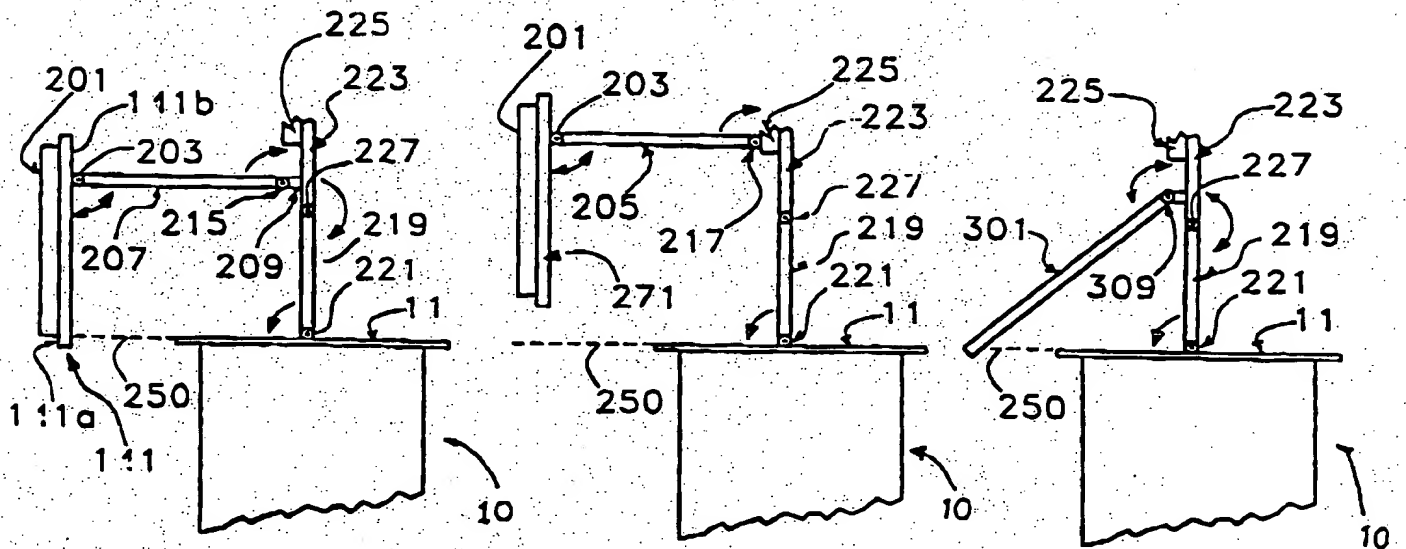


Fig. 7

Fig. 8

Fig. 9

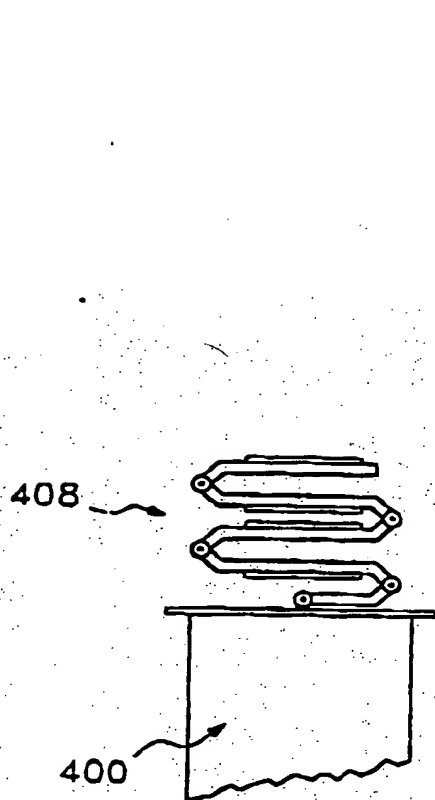


Fig. 10a
PRIOR ART

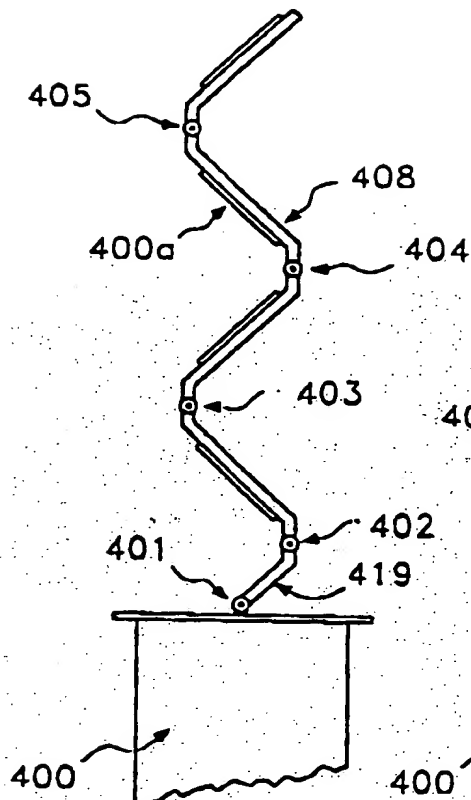


Fig. 10b
PRIOR ART

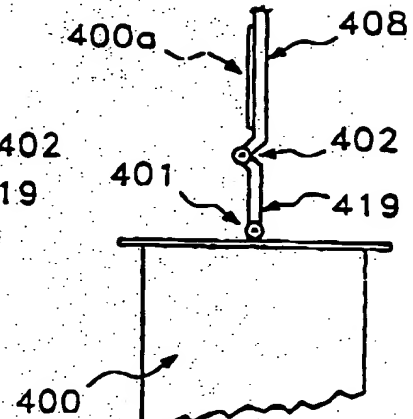


Fig. 10c
PRIOR ART

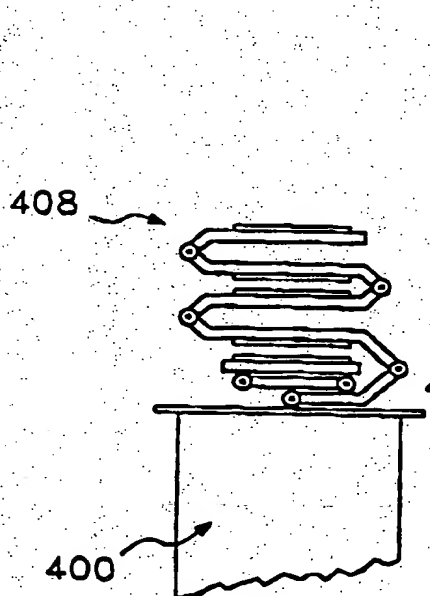


Fig. 11a

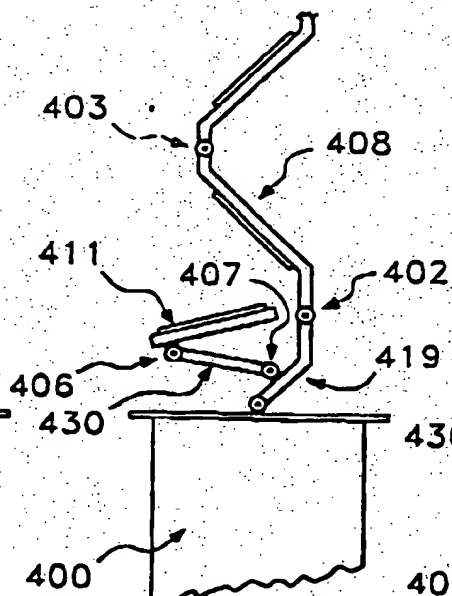


Fig. 11b

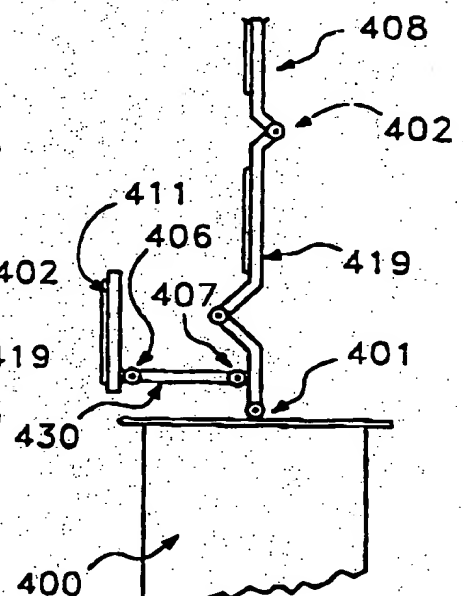


Fig. 11c

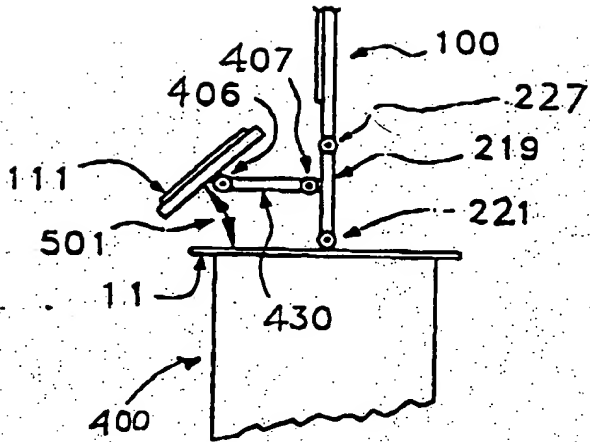


Fig. 12a

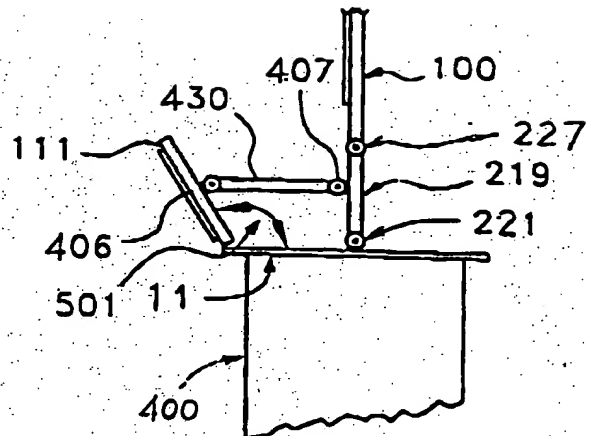


Fig. 12b

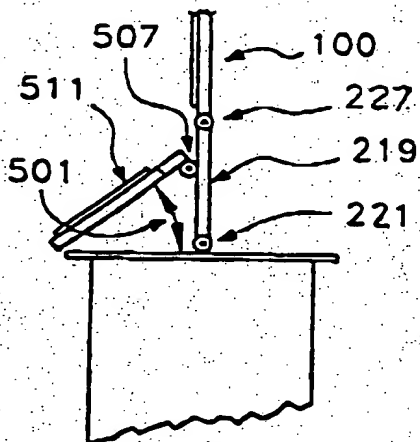


Fig. 13

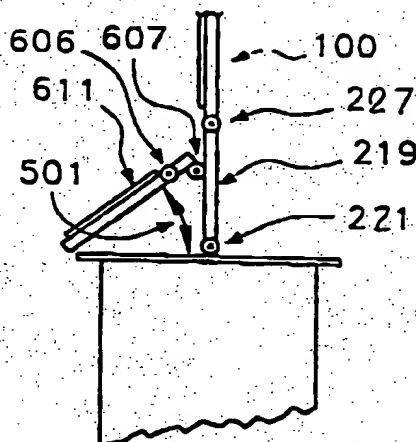


Fig. 14a

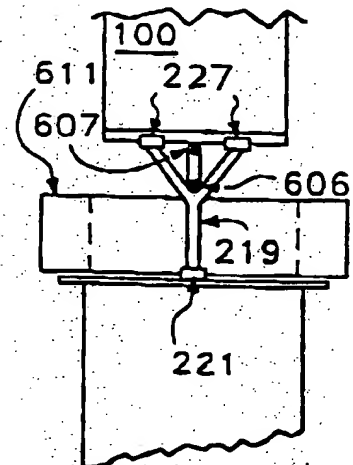


Fig. 14b

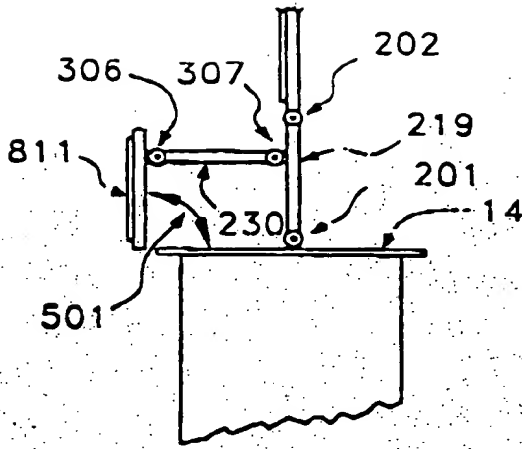


Fig. 15a

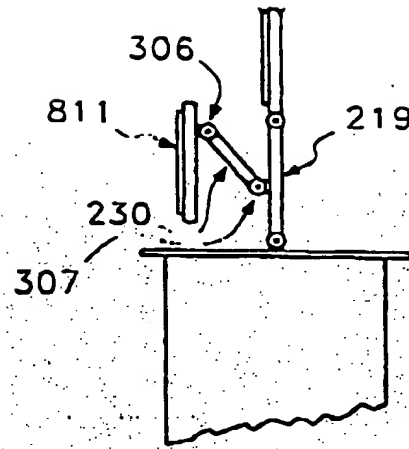


Fig. 15b

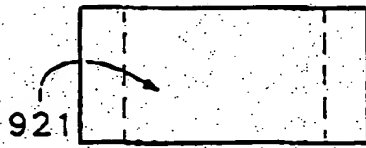


Fig. 16a



Fig. 17a

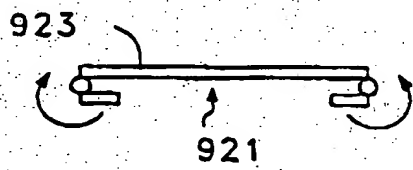


Fig. 16b

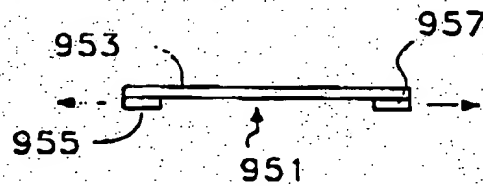


Fig. 17b

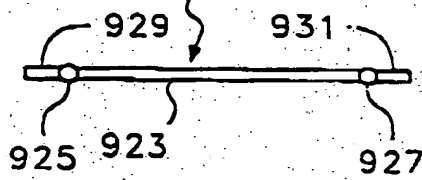


Fig. 16c

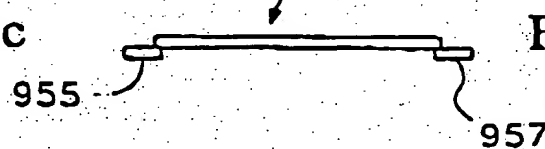


Fig. 17c

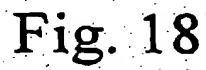


Fig. 18

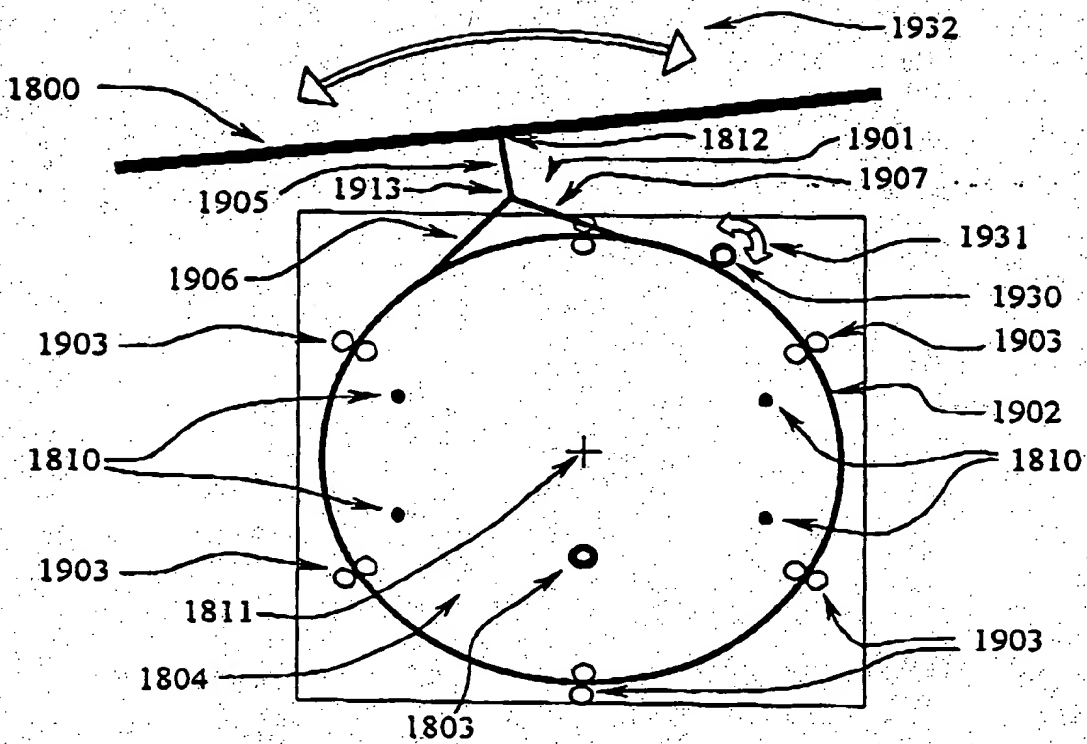


Fig. 19

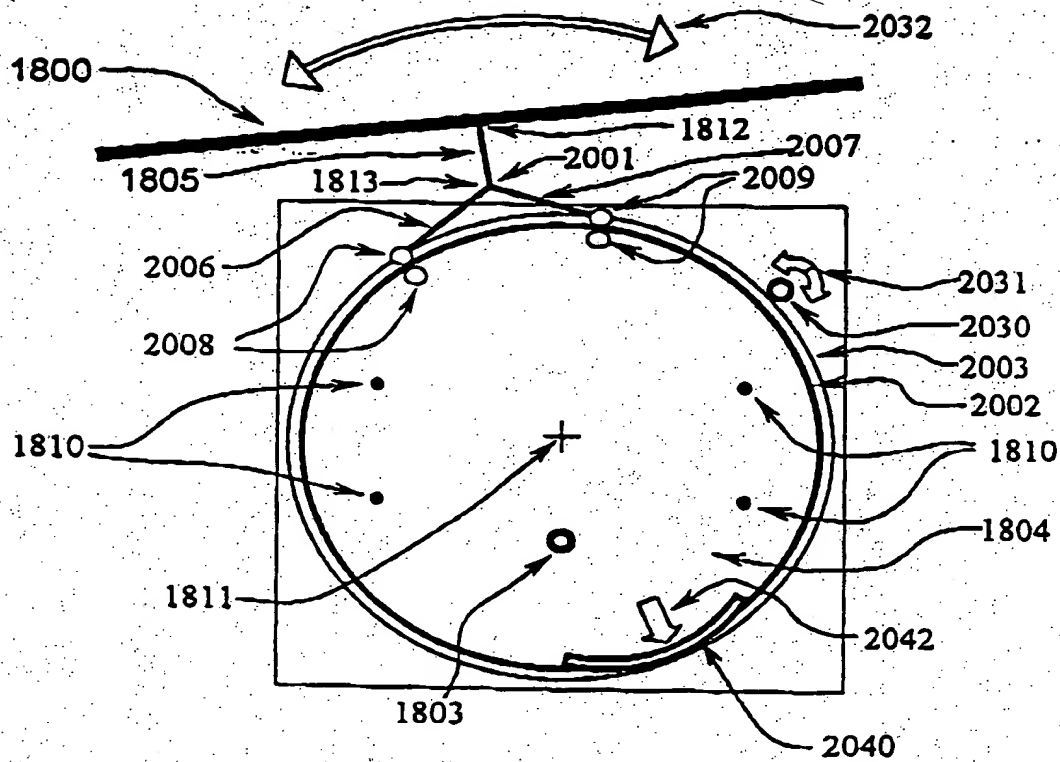


Fig. 20

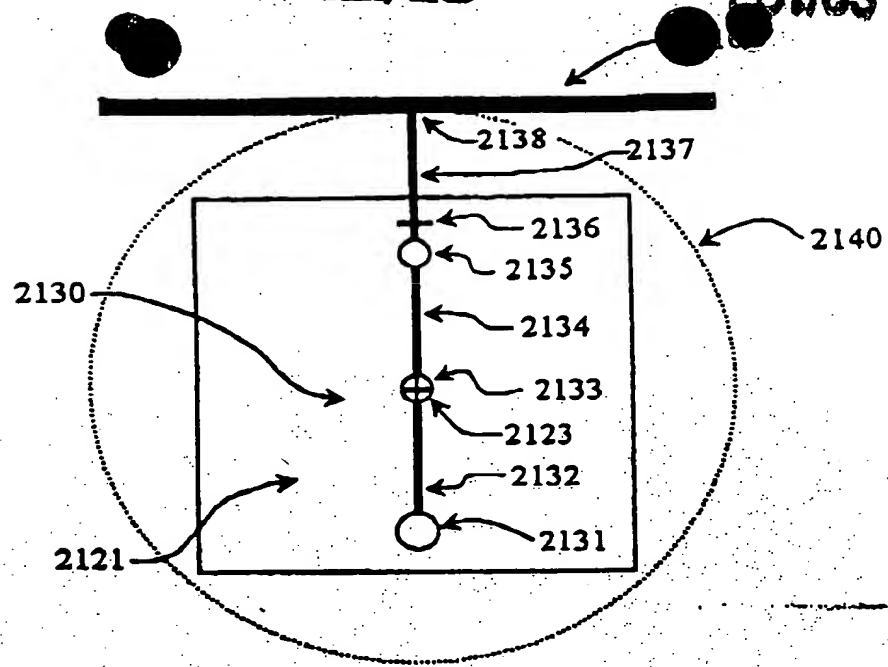


Fig. 21

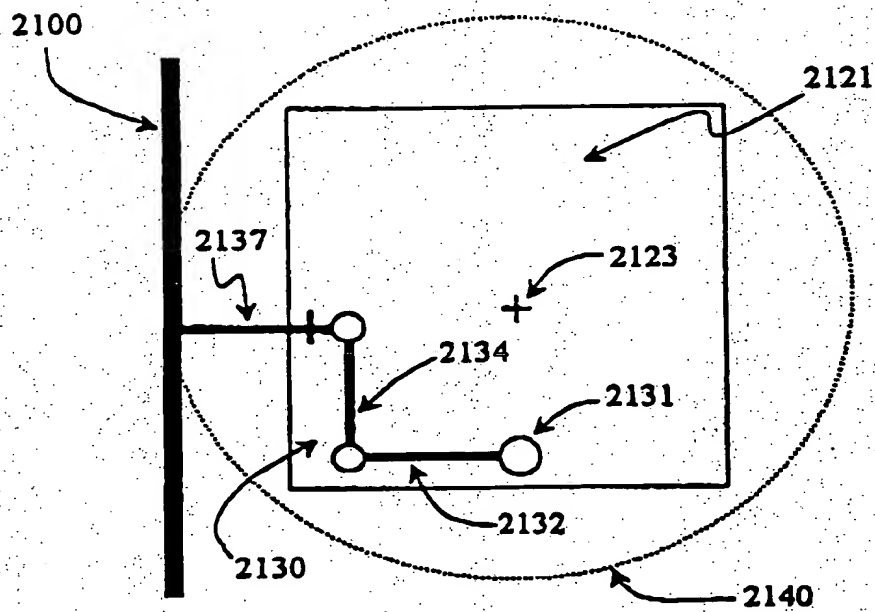


Fig. 22

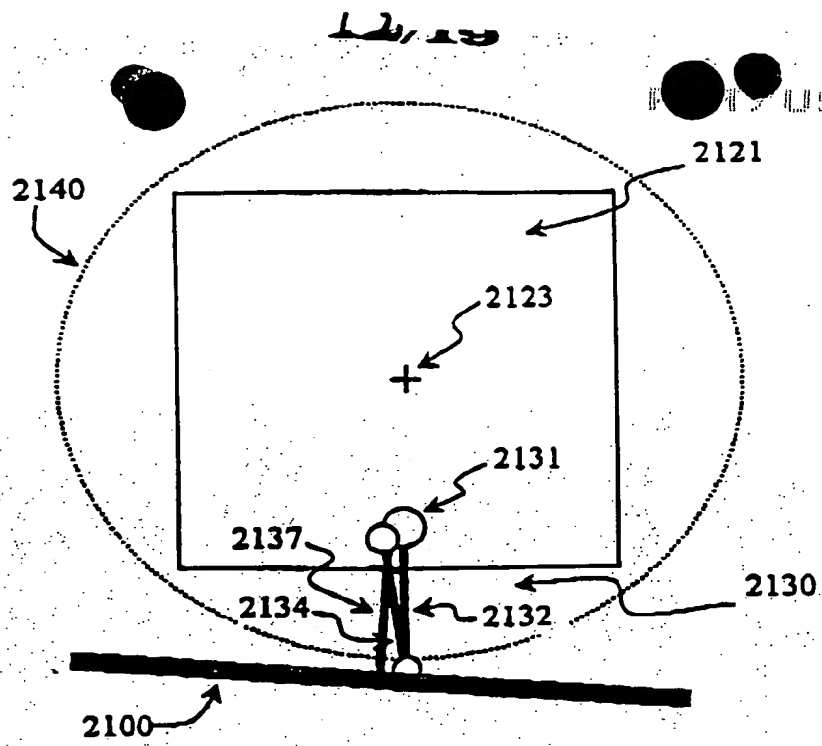


Fig. 23

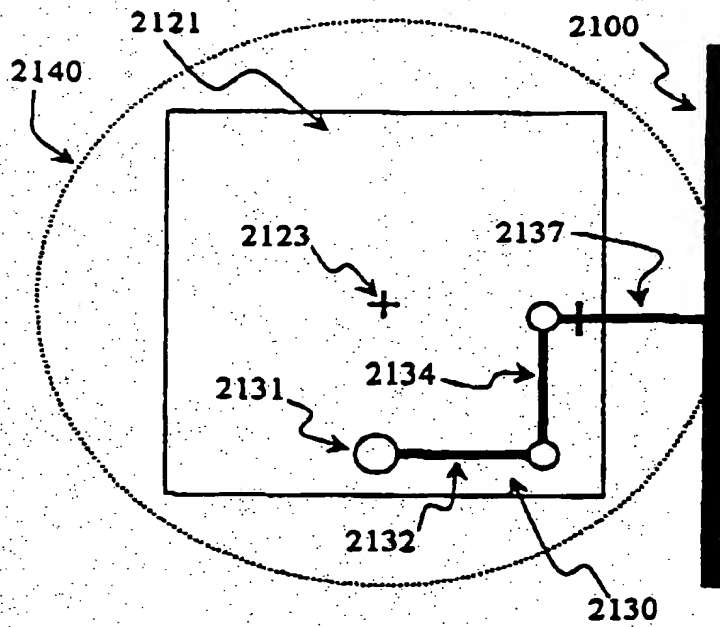


Fig. 24

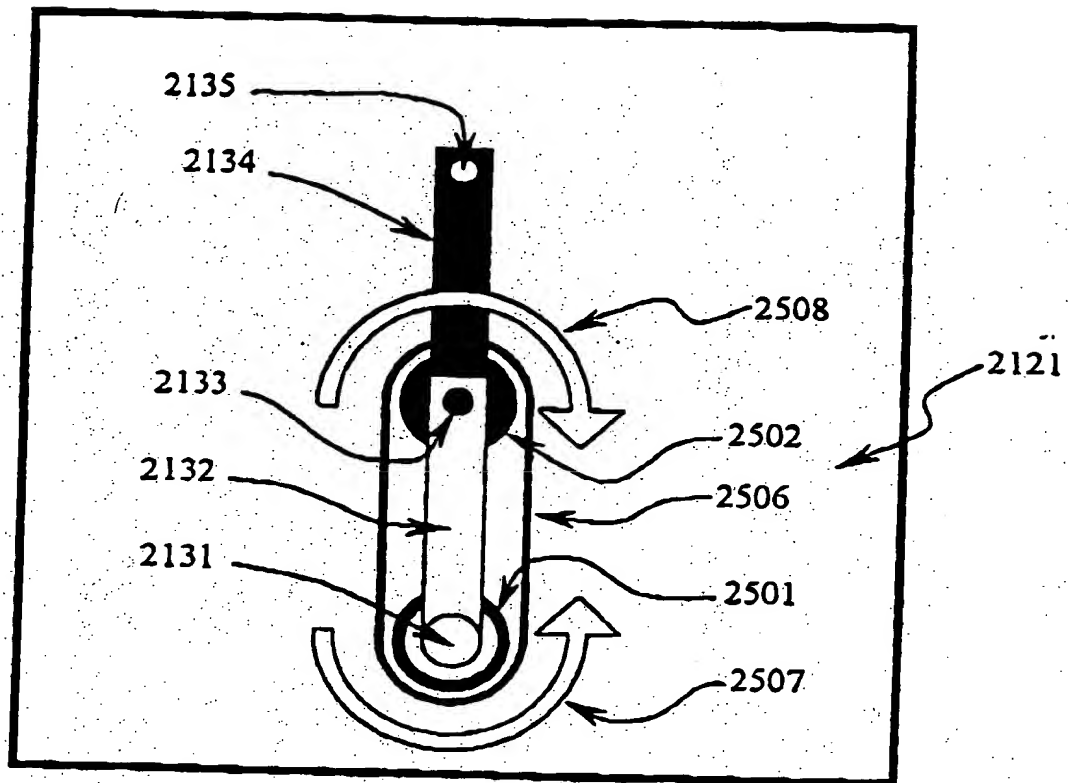


Fig. 25

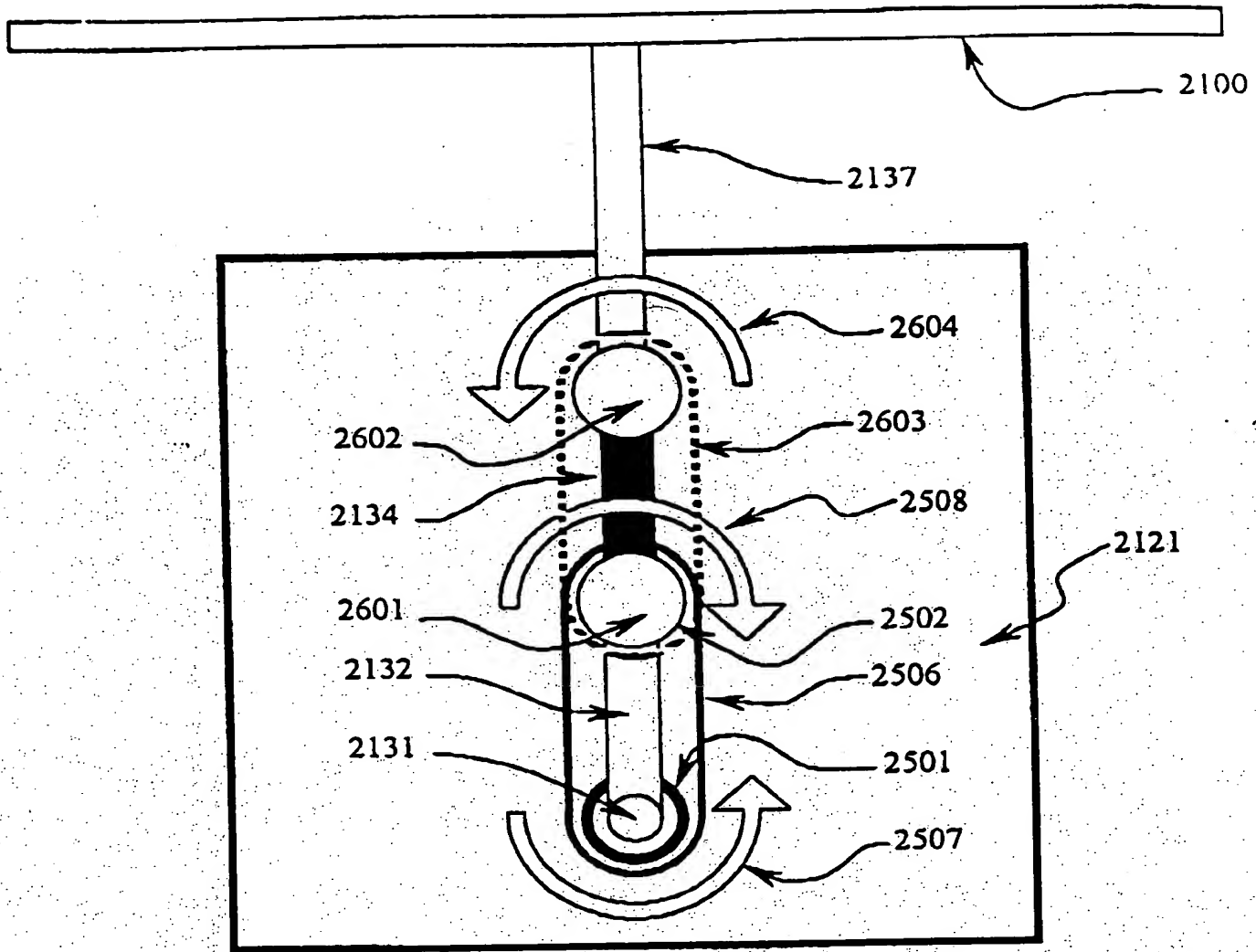


Fig. 26

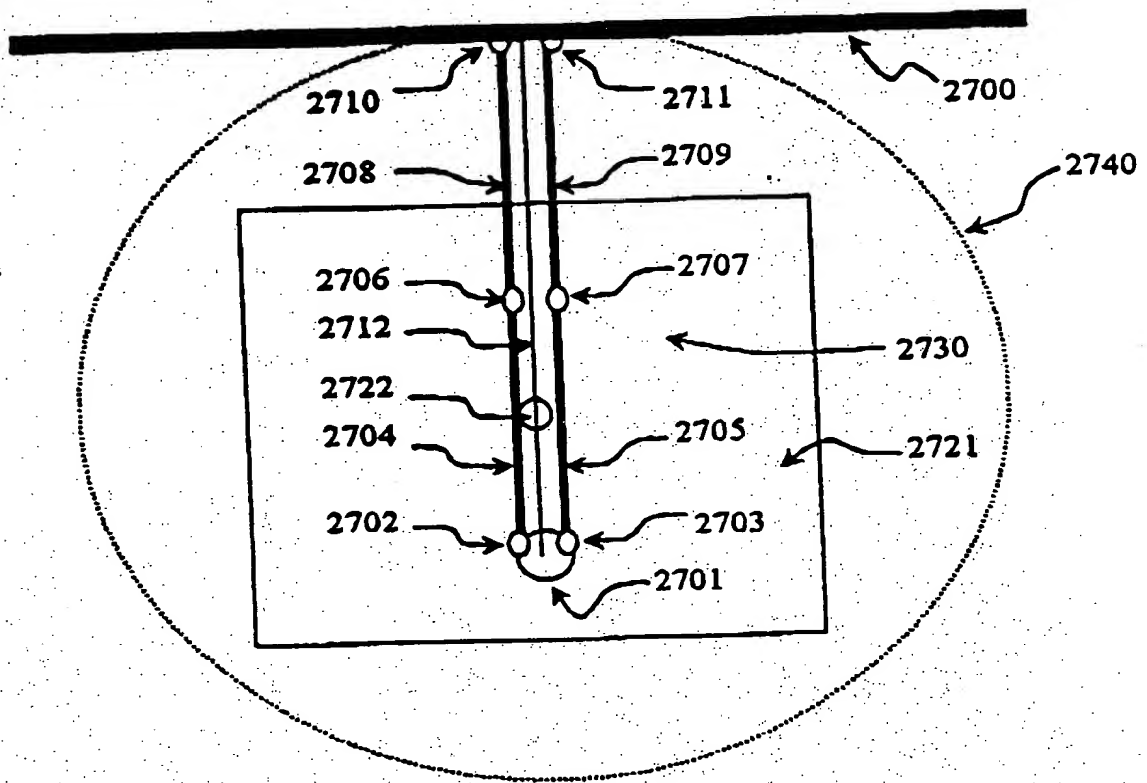
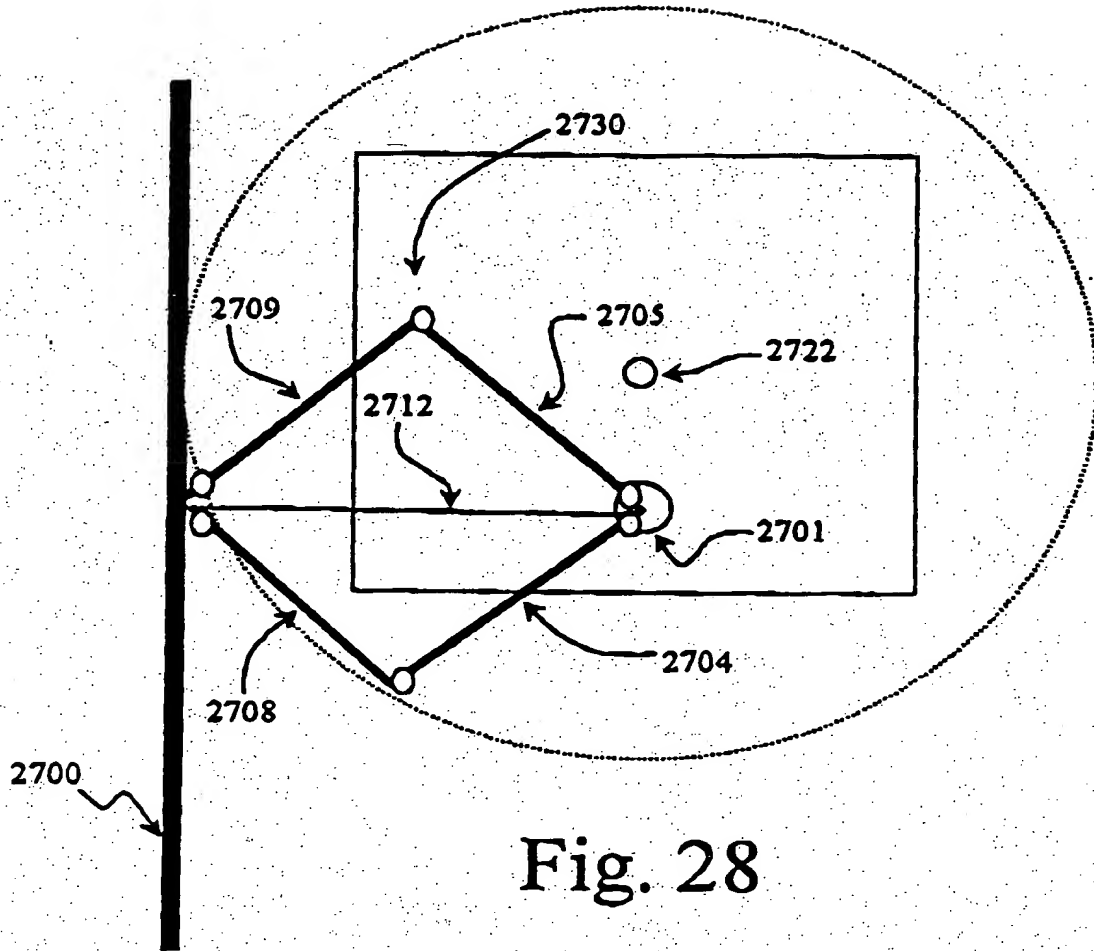


Fig. 27



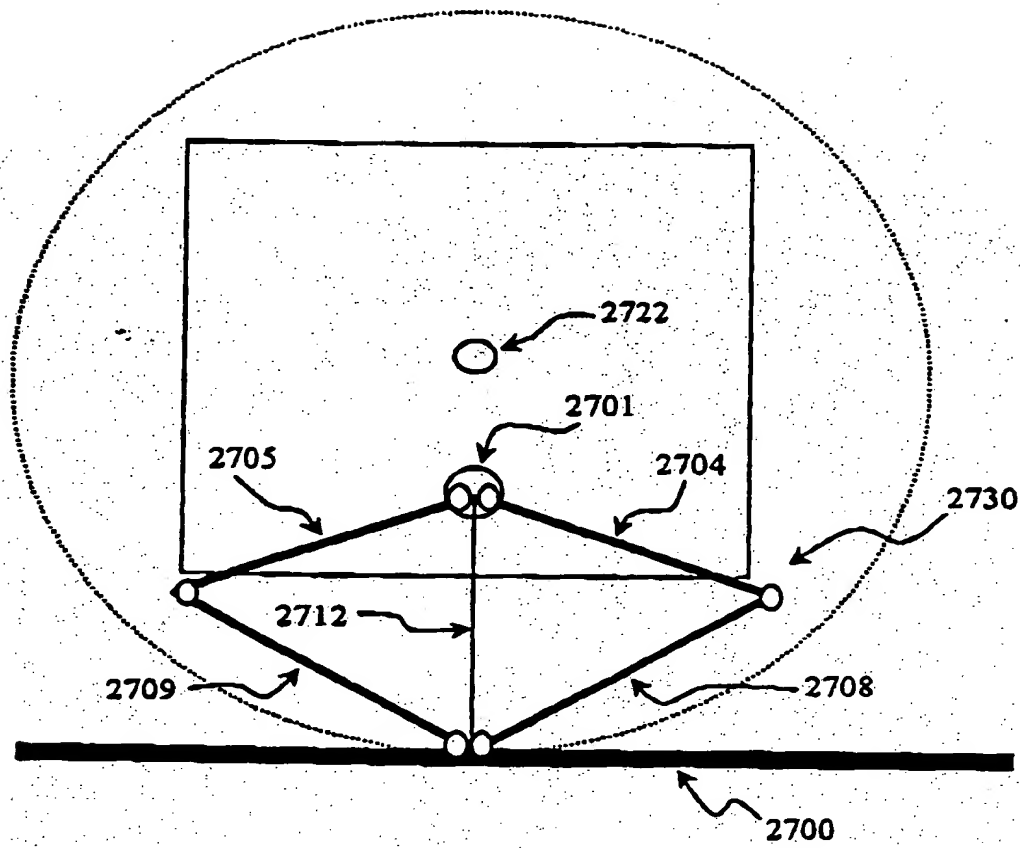


Fig. 29

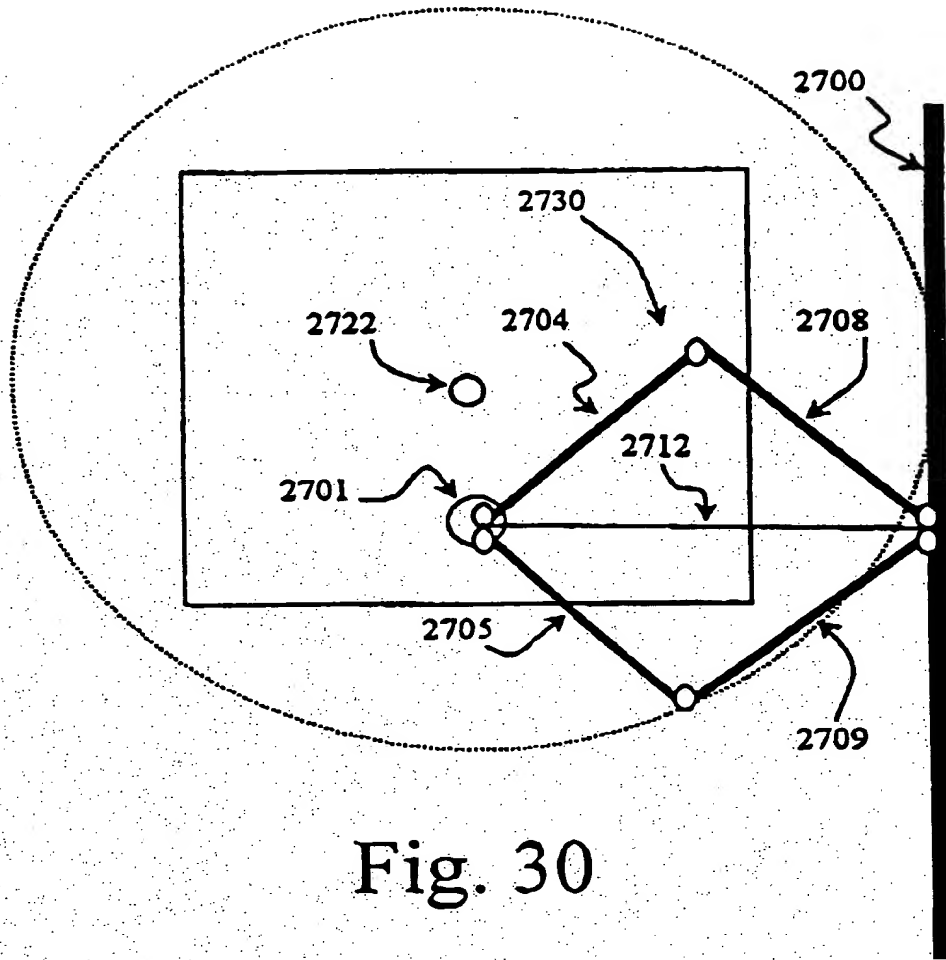
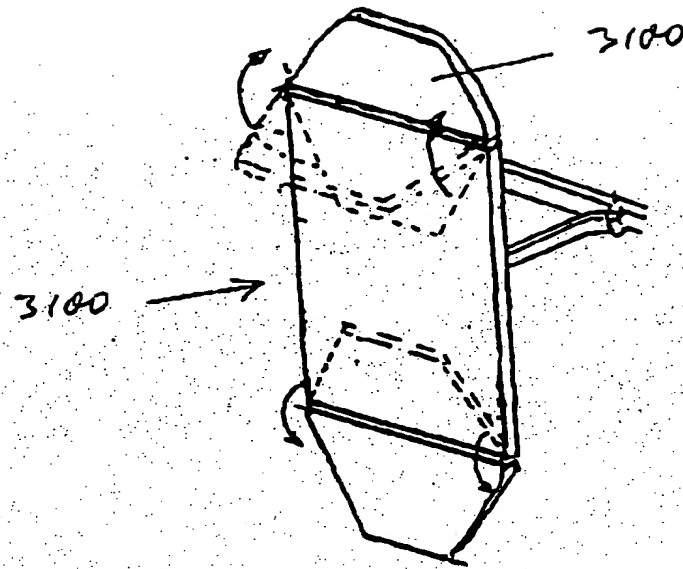
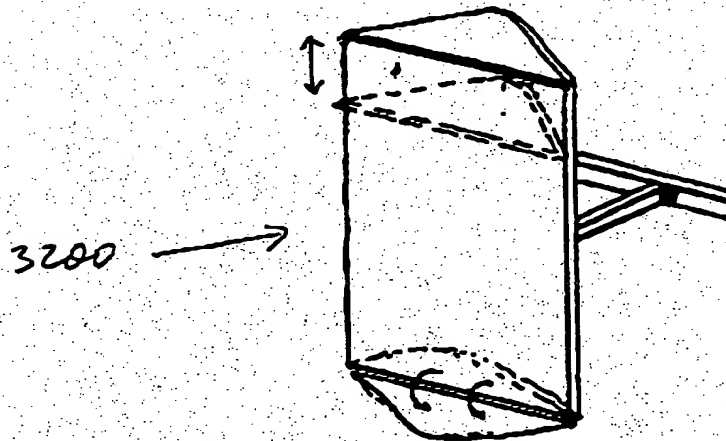


Fig. 30

**Fig. 31****Fig. 32**

PCT

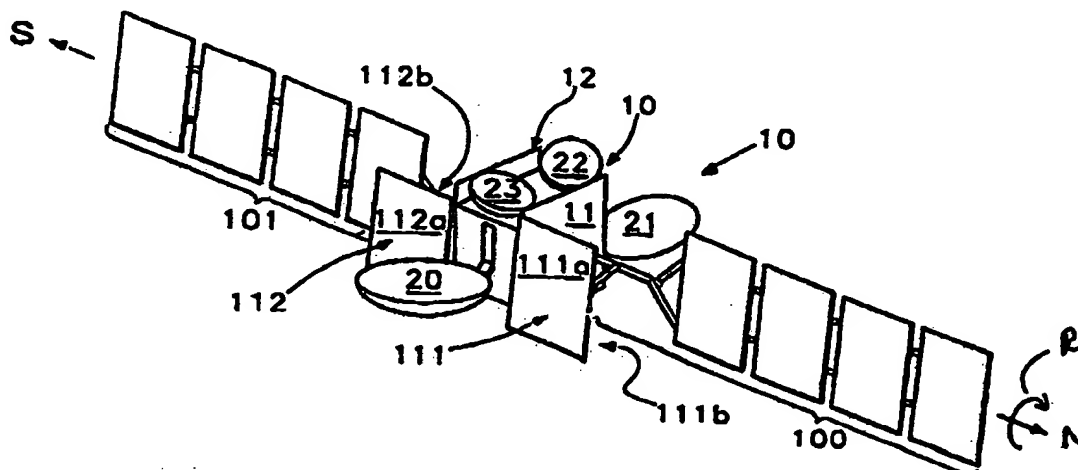
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(54) Title: SPACECRAFT



(57) Abstract

A spacecraft having a sun ray blocker device (111, 112, 141, 271, 301, 411, 511, 611, 811, 921, 951, 1800, 2100, 2700) for shading a thermal radiator surface (11, 12) of the spacecraft in which the sun ray blocker device is movable in relation to the thermal radiator surface to keep the surface substantially in shade without substantially blocking thermal radiation from the thermal radiator surface to deep space. Preferably a sun-facing side (111a, 112a) of the sun ray blocker device is thermally insulated from an opposed side (111b, 112b) to reduce thermal radiation from the sun ray blocker device to the thermal radiator surface and the sun ray blocker device is also preferably deployable in orbit after launch.

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SPACECRAFT

5 The present invention relates to a spacecraft and particularly to a spacecraft having a sun ray blocker device for shading thermal radiator surfaces on said spacecraft from solar heating.

10 The following patents are generally representative of the prior art in the broad fields of solar array related sun shields, solar array deployment mechanisms, and the thermal control of radiator surfaces for various types of spacecraft.

15 United States Patent 4,133,502 to Andrew Anchutin describes a plurality of arrays of solar cells which are symmetrically stored about a spacecraft during launch to provide symmetrical loading. When the spacecraft is in operational configuration, the solar arrays are deployed adjacent each other on one side of the spacecraft to effectively form a single array and the single array may be oriented to face the Sun by a common drive mechanism.

25 United States Patent 4,508,297 to Guy G. Mouilhayrat et al, describes an equatorial orbit satellite with solar panels having blades with a median line inclined at a certain angle relative to the equatorial plane. Thus, the field of vision of the antennas is free and disturbing torques become acceptable.

30 United States Patent Number 5,372,183 to Harold P. Strickberger describes a spacecraft adapted for operation

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in a low inclination angle earth orbit which comprises north, south, east and west panels defining a spacecraft interior volume. The north and south panels are oppositely disposed with respect to each other and the east and west panels are oppositely disposed with respect to each other. The spacecraft interior volume generally and preferably lacks structural elements that substantially restrict thermal radiation among the panels. The north and south panels, to which spacecraft equipment is usually mounted, each include conductive heat pipes for reducing the temperature difference across each panel. The exterior surfaces of the north, south, east and west panels have a covering, preferably of optical solar reflectors (OSRs), for radiating thermal energy therefrom, wherein the OSRs have a solar absorptivity that is substantially less than their thermal emissivity. The interior surfaces of the north, south, east and west panels have a covering for effectively radiating thermal energy between and among the panels across the interior volume.

United States Patent 4,725,023 to Haruo Shiki describes a geostatic satellite which comprises a spinning drum for stabilization which spins around an axis of rotation which is parallel to the axis of the Earth. A paddle member loaded with solar cells is directly rotatable about the same axis and is controlled such that the solar cells face the Sun. A de-spun platform supports communication gear and maintains the gear pointed to a relatively fixed point on Earth. A shading device for shading the electronics laden de-spun platform from the Sun is attached to the paddle member

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and rotatable therewith. Thereby, the shading device will always be disposed between the Sun and the de-spun platform. However, the shading device also blocks thermal radiation from the platform and also itself heats up in sunlight and radiates heat towards the platform, decreasing the efficiencies of heat transfer from the spacecraft to space.

Notwithstanding the prior art, the present invention is neither taught nor rendered obvious thereby.

It is an object of this invention substantially to reduce or eliminate the direct and indirect solar heating of certain spacecraft radiator-panels, and to also minimize the magnitude of any reduction in the radiative-view-factor of the (shielded) radiator panel. In order to achieve that objective, the materials and design selected for the sun ray blocker device, which will be discussed below, should ideally provide all of the following: minimum blockage of the field-of-view to deep space of its associated radiator surface(s), low absorption of the solar energy incident on its front (sunward) surface, high radiation of absorbed thermal energy back to space, and high insulation of heat between the front (sunward) and back (anti-sunward) sides of the sun ray blocker device.

It is also desirable to provide a sun ray blocker device that is capable of greatly reducing or eliminating solar energy incident on those sides of certain spacecraft relative to which the Sun direction makes a low angle. The types of spacecraft to which the present

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invention applies include some spacecraft for operation in equatorial or low inclination orbits, and in sun synchronous orbits with low orbit-sun angles. In the case of three-axis stabilized, Earth-pointing, geostationary spacecraft for example, these shaded sides are either or both of the north and south main-body panels. In the case of the sun synchronous spacecraft for example, the shaded sides are either or both of the sides or main-body panels that face out along the pitch axis (i.e. that face parallel to the orbit normal and anti-normal). The present invention can also be applied to types of spacecraft, other than geostationary and sun synchronous types, upon which the solar illumination is incident at low angles relative to thermal radiator surface. In those spacecraft it is those main thermal radiator surface that can be shaded by the present invention device.

According to a first embodiment of the invention there is provided a spacecraft for orbiting a sunlit celestial body, the spacecraft including a thermal radiator surface for radiating heat from the spacecraft into space, and a sun-ray blocker device mounted on said spacecraft for shielding said thermal radiator surface from rays of sunlight, characterised in that said sun ray blocker device is locatable for placing in shadow substantially the whole of the thermal radiator surface from sunlight without substantially impeding thermal radiation from said thermal radiator surface into space.

Preferably an effective radiation view factor for thermal radiation from the thermal radiator surface

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(11,12,1804, 2121,2721) to deep space is significantly greater than corresponding geometrical radiation view factor to deep space, and in particular, for a geostationary spacecraft where the geometrical radiation view factor to deep space is 0.65, the effective radiation view factor to deep space is at least 0.87.

A preferred inventive feature will be seen to reside in the sun ray blocker device including at least one sun blocker panel having a sun-facing surface and an opposed anti-sun-facing surface, wherein the sun-facing surface is thermally insulated from the opposed surface.

Conveniently the sun-facing surface is thermally insulated from the opposed surface by a multi-layer insulation blanket.

Advantageously the sun-facing surface has a low solar energy absorptivity of less than 0.5.

Advantageously the sun-facing surface includes a solar cell panel for supplying electrical power to the spacecraft.

Preferably the sun-facing surface has a high thermal emissivity of higher than 0.7.

A preferred inventive feature will be seen to reside in the sun ray blocker device being moveable between a stowed, non-operative position and a deployed operative position.

Conveniently the sun ray blocker device includes an attachment arm for attaching the sun blocker panel to the spacecraft.

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Advantageously the attachment arm is attached by a hinge means to the sun blocker panel and/or by a second hinge means to the spacecraft.

Advantageously the sun ray blocker device includes a
5 motor for moving the sun ray blocker device between the stowed position and the deployed position.

Preferably locating means are provided for locating the sun ray blocker device with respect to the thermal radiator surface which include adjustment means to
10 maintain the majority of the thermal radiator surface in shadow irrespective of changes in the attitude and/or orbit of the spacecraft.

Advantageously the adjustment means includes carriage means (1801, 1901, 2001) for carrying the sun
15 blocker panel (1800, 1900, 2000) and transport means (1802, 1808, 1903, 1904, 2003, 2006) for moving the carriage with respect to the spacecraft.

Conveniently the transport means includes rail means (1802) and the carriage means (1801) includes drive means
20 to drive the carriage along the rail means.

Preferably the transport means includes an annulus rotatable in circular path defined by bearing means, the annulus being driveable by drive means to move the carriage along the path defined by the bearing means.

25 Alternatively the transport means includes rail means (1902) and belt means (1903) connected to the carriage means (1901), the belt means being driven by

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drive means (1904) to move the carriage means along the rail means (1902).

Conveniently the adjustment means includes a variable length attachment arm (2101, 2703) for attachment
5 of the sun blocker panel (2100, 2700) to a solar cell array assembly (2103, 2701) for rotation with the solar cell array assembly, such that the distance of the sun blocker panel from the solar cell array assembly may be varied during rotation.

10 Alternatively the spacecraft has a solar cell array adapted for tracking movements of the sun relative to the spacecraft, wherein the adjustment of the location of the sun ray blocker device in relation to the thermal radiator surface is synchronised with the tracking
15 movement of the solar cell array, when in normal operation.

Conveniently the sun ray blocker device is mounted on the solar cell array or on means carry said solar cell array.

20 Advantageously the solar cell array tracks the movement of the sun by rotation of the solar cell array about an axis of rotation of the solar cell array such that the sun blocker panel also rotates about said axis of rotation of the solar cell array.

25 Conveniently the thermal radiator surface is orthogonal to the axis of rotation of the solar cell array so that the sun blocker panel rotates about an axis normal to the thermal radiator surface.

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Advantageously adjustment means includes a variable length attachment arm for attachment of the sun blocker panel to the spacecraft.

5 Advantageously the attachment arm is a scissor arm (2703).

Alternatively the attachment arm (2101) is formed of articulated portions (2104, 2105, 2106) which may be mutually articulated during rotation to vary an effective length of the attachment arm.

10 Conveniently adjustment means for attachment of the sun blocker panel to a solar cell array assembly are such that a distance between the sun blocker panel and the solar cell array assembly may be varied during rotation of the sun blocker panel.

15 Conveniently means are provided for adjusting the size of the sun blocker panel.

Conveniently the spacecraft includes control means for controlling the spacecraft so as to maintain an angle between a sun line and the thermal radiator surface below
20 a predetermined angle by adjustment of the orbit and/or attitude of the spacecraft in use.

Preferably the predetermined angle is 60 degrees.

More preferably the predetermined angle is 45 degrees.

25 Most preferably the predetermined angle is 23.5 degrees.

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Advantageously the control means is adapted to maintain the thermal radiator surface substantially parallel to a plane of an orbit of the spacecraft.

Alternatively the control means is adapted to
5 maintain the spacecraft in a sun synchronous orbit.

Alternatively, the control means is adapted to maintain the spacecraft in an equatorial or low-inclination orbit.

According to another embodiment of the invention
10 there is provided in a three axis stabilised spacecraft for orbiting about a planet and having at least one solar cell assembly having at least one solar cell panel, and being a north solar cell panel assembly or a south solar cell panel assembly, said at least one solar cell panel
15 assembly being mounted on an axle so as to be controllably rotated from said spacecraft about an axis of rotation so as to face the sun, said spacecraft having a nadir panel which is generally pointing to the centre of the planet, an opposite panel known as a zenith panel,
20 which faces away from the centre of the planet and sharing the same planar normal vector as said nadir panel, an east panel and a west panel, said east panel and said west panel having their planar normal vector laying on a orbital plane pointing to the velocity vector
25 of the spacecraft generally tangential to the direction of travel on the orbit, and a north panel and a south panel, said north panel and said south panel having their planar normal vector generally perpendicular to the orbit plane and parallel to the axis of rotation of the planet,

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said solar cell panel extending outwardly from said spacecraft, the improvement which comprises:

attaching at least one sun ray blocker device to said at least one solar cell panel, said at least one device
5 being either a north blocker device or being a south blocker device and corresponding to said at least one solar cell panel, each of said at least one sun ray blocker device being positioned forwardly from and offset relative to a solar cell surface of a solar cell panel
10 and at a predetermined angle to either of said north panel and said south panel, said north panel or said south panel, said sun ray blocker device being positioned so as to cast a shadow on at least a majority of the exposed surface of its corresponding north or south panel
15 during solar exposure thereto.

According to another embodiment of the invention there is provided in a three axis stabilised low inclination orbit spacecraft for orbiting about the earth
20 and having two sets of solar cell array assemblies having solar cell arrays, one set being a north solar array assembly and the other being a south solar array assembly, said assemblies each being mounted on an axle so as to be controllably rotated from said spacecraft
25 about an axis of rotation so as to face the sun, said spacecraft having an earth panel which is generally pointing to the centre of the earth, an opposite panel known as a zenith panel, which faces away from the centre of the earth and sharing the same planar normal vector as
30 said earth panel, an east panel and a west panel, said east panel and said west panel having their planar normal vector laying on an orbital plane pointing to the

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velocity vector of the spacecraft generally tangential to the direction of travel on the orbit, and a north panel and a south panel, said north panel and said south panel having their planar normal vector generally perpendicular to the orbit plane and parallel to the axis of rotation of the earth, said solar cell panel extending outwardly from said spacecraft, the improvement which comprises:

attaching at least one sun ray blocker device to each of said north solar array and said south solar array, one device being a north device and another device being a south device, each of said sun ray blocker devices being in the form of a panel and being positioned forwardly and offset relative to the solar cell surface of a solar ray and at a predetermined angle to said north panel and said south panel, said north blocker device being positioned so as to cast a shadow on at least a majority of the exposed surface of said north panel during solar exposure thereto, and said south blocker device being positioned so as to cast a shadow on the exposed surface of said south panel during solar exposure thereto.

The present invention preferably provides a sun-synchronous sun ray blocker device (not to be confused with sun synchronous orbits referred to elsewhere herein) for use in a spacecraft designed to orbit around a planet with solar incidence at low angles to their thermal radiator surfaces, i.e. with sun directions close to the planes of the individual radiator surfaces. Preferred embodiments of the present invention are spacecraft for operating in an orbit plane oriented at a

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low angle (or within a range of low angles) to the sun direction, the said spacecraft having a thermal radiator surface that is oriented approximately parallel to the orbit plane and a solar array assembly that is rotated
5 about an axis approximately perpendicular to the orbit plane nominally at the orbital rate. Examples of appropriate orbits are: (a) low inclination orbits around the Earth (including nominally equatorial orbits), and
10 (b) sun synchronous orbits with low orbit-sun angles (which around Earth and Mars, for example, are nominally polar orbits). The term "spacecraft" as used herein includes satellites and other space bound vehicles.

Mounted on any spacecraft to which the present
15 invention is applied is at least one device for blocker sun rays and thereby preventing them from directly impinging on a radiator surfaces of the spacecraft.

In many embodiments of the present invention the
20 individual spacecraft will have at least one solar array assembly (comprised of solar cell panels and rotary axial booms) which may be used as mounting support for the sun ray blocker device(s), so that the combination assembly of solar array assembly and sun blocker device(s) is
25 operationally controllably rotated together as an integral unit to track the Sun throughout the orbital revolutions of the spacecraft, said solar array assembly being mounted on the spacecraft so that operationally in orbit it can be rotated about an axis that is maintained
30 oriented approximately perpendicular to the orbit plane in a manner such that the solar-cell side of the solar cell panels is maintained sun facing and substantially

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perpendicular to the Sun direction. Because then the sun ray blocker device may rotate integrally with the solar array assembly, it is able to prevent sun rays from directly impinging on all or part of an associated thermal radiator surface(s), whose plane is maintained approximately parallel to the orbit plane, thus creating a continuous steady and benign thermal environment for the thermal radiator surface.

10 Spacecraft operated in orbits with low orbit-Sun angles (the angle between the orbit plane and the Sun) are prime candidates for application of the current invention device. Various different frequently-utilized types of orbits feature low orbit-Sun angles. Currently, 15 among the most utilized types of orbits with low orbit-Sun angles are (a) low inclination and nominally-equatorial orbits, including geosynchronous orbits, and (b) the subset of sun synchronous orbits with low orbit-Sun angles. Sun synchronous orbits maintain a little- 20 varying orbit-Sun angle as the planet revolves around the Sun. The Earth revolves around the Sun once per year.

One type of spacecraft operated in a nominally equatorial orbit around a planet, e.g. the Earth, or in 25 particular, a geosynchronous orbit, is frequently used for the purposes of telecommunications, broadcasting, monitoring ecological conditions, global positioning, remote sensing, surveillance and weather forecasting.

30 Another type of satellite operated in nominally sun synchronous orbits around planets, e.g. the Earth, with low orbit-Sun angles, is frequently used for the purposes

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of weather monitoring and remote sensing of the planet and its atmosphere. Some of the benefits of these sun synchronous orbits are: low spacecraft altitudes, frequent over-flight of the planet within close proximity of virtually all latitudes and longitudes, and near constant angle of solar illumination on the day side of the orbit.

Means of adjusting the attitude and orbit of spacecraft are well known, for example, are described in "Principals of Communication Satellites" by Gary D Gordan and Walter L Morgan published by John Wiley & Sons 1993, pages 12-14, 55-58 and in "Spacecraft Attitudes, Termination and Control" by James R Wertz published by Kluwer Academic Publishers 1978. Attitude and orbit control may for example be provided by the use of thrusters and/or momentum or reaction wheels.

Typically, the attitude (i.e. the orientation) of these types of satellite is controlled so that as the satellite orbits the planet part of its payload equipment steadily faces approximately toward the center of the planet, while the solar arrays are maintained sun pointing. The attitude (orientation) control systems of such spacecraft belong to various classifications that are well known within the space industry. For example, two of the more currently prominent types of attitude control system are commonly referred to as "three-axis-stabilized" control systems and "spin stabilized" control systems. The present invention device functions independently of the type of attitude control system, and independently of the orientation of spacecraft equipment

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other than the orientation of the thermal radiator surfaces that the device shields from solar energy. In these types of spacecraft, the performance of the present invention device is generally better the closer the
5 shadowed thermal radiator surface is to being parallel to the orbit plane (which in these types of spacecraft is maintainable at a low angle to the sun line).

Hereinafter, the concept of a "model spacecraft" is defined and employed in order to avoid the distraction of
10 multiple lengthy descriptions of diverse spacecraft to which the present invention device may be applied. The model spacecraft is used herein, somewhat like a tailor's dummy, in order to facilitate the illustration and explanation of features, functions, and examples of
15 applications of the present invention device.

By definition the model spacecraft has a basic, deployed (i.e. unfolded), structural configuration that is typical of many current three axis stabilized
20 satellites, and a corresponding operational mode that is typical of a geostationary Earthpointing spacecraft. Note that this definition was selected on the basis of current estimates of the most frequent future application of the present invention device. The definition of the
25 model spacecraft could equally well have been based on typical characteristics of another relevant type of spacecraft, for example an Earth-pointing spacecraft in a sun synchronous orbit with a low orbit-Sun angle.

30 Referring to FIGURES 1 and 5, the basic structural configuration of the model spacecraft is based on a main body in the form of a hollow, right parallelepiped. For

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the stated purposes of using the concept of the "model spacecraft" herein, it is useful to consider the main body as being comprised of six principal, planar, structural panels. The external surfaces of one opposing pair of the six panels that form the main body of the model spacecraft constitute the mounting sites for the thermal radiator surfaces that are shielded from direct solar heating by means of the present invention device. Mounted on one or each of these two radiator-bearing panels, and extending perpendicularly outwards therefrom, is a solar array assembly, comprised of a rotary solar array boom to which are attached solar cell panels.

That is not to say that application of the present invention device is limited to spacecraft resembling the structural configuration and operational mode of the model spacecraft. For example, the present invention device is also applicable to: sun synchronous spacecraft in orbits with low orbit-Sun angles; spin stabilized spacecraft; spacecraft with polyhedral and/or irregular structures; spacecraft that are not nadir pointing; spacecraft with solar arrays that deploy and subsequently lie along axes that are not perpendicular to the radiator-bearing panels; etc.

25

Much of the text herein that supports the accompanying claims is written with reference to the model spacecraft. Regardless, the supporting text also applies to applications of the present invention device to other suitable types of spacecraft. For example, the principal relevant difference between many suitable sun synchronous spacecraft (for polar orbits at Earth and

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Mars at least, where the polar axes lie close to the planes of sun-synchronous orbits around them) and the model spacecraft is that the plane of the thermal-radiator surface(s) that is shaded by the present invention device is approximately parallel to the axis of rotation of the planet (rather than perpendicular to the axis of rotation of the planet as for geostationary spacecraft like the model spacecraft). Accordingly, the supporting text describing spacecraft like the model spacecraft is easily read as it relates to these suitable sun synchronous spacecraft, for example by substituting in "pitch axis panel" or "orbit normal panel" to replace "north/south panel", and substituting in "velocity panel" or "roll axis panel" to replace "east/west panel".

15

In order to provide functional services in an operational orbit, the model spacecraft has one of the six structural panels of its main body continuously facing the planet, e.g. the Earth. That panel is referred to as the earth panel or the nadir panel. A vector that is outward-from and normal-to the earth panel is parallel to the (body fixed) yaw axis of the spacecraft. In the model spacecraft the yaw axis is maintained nominally parallel to the nadir direction, i.e. is nominally pointed toward the center of the planet. Because the model spacecraft operates in a geosynchronous orbit, which is nominally circular, the yaw axis of the model spacecraft is maintained nominally perpendicular to the velocity vector of the spacecraft. A vector that is outward-from and normal-to the plane of the structural panel opposite the nadir panel is parallel to the negative yaw axis. That main-body panel of three

30

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axis stabilised Earth pointing geostationary spacecraft like the model spacecraft is usually referred to as the zenith panel or anti-earth panel.

5 Another opposing pair out of the six structural panels comprising the main body of the model spacecraft are oriented so that, nominally or approximately, vectors that are outward-from and normal-to their planes lie in the orbital plane and are perpendicular to the yaw axis
10 and to the nadir and zenith directions. These outward normal vectors are parallel and anti-parallel to the positive and negative (body fixed) roll axes of the spacecraft. Because the geosynchronous orbit of the model spacecraft is circular, the roll axes of the model
15 spacecraft nominally coincide with the velocity and anti-velocity vectors of the orbital motion. For geostationary spacecraft the velocity of the spacecraft is eastward; and consequently these two main-body panels of spacecraft like the model spacecraft are generally
20 referred to as the east and west panels.

 Accordingly, the remaining two structural panels comprising the main body of the model spacecraft are oriented so that their planes are nominally or
25 approximately parallel to the orbit plane. Vectors that are outward-from and normal-to the planes of these panels are parallel to the positive and negative (body fixed) pitch axes of the spacecraft. Since the geosynchronous orbit of the model spacecraft is nominally equatorial,
30 the pitch axes of the model spacecraft are approximately parallel and anti-parallel to the spin axis of the Earth; and accordingly these two main-body panels of spacecraft

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like the model spacecraft are referred to as the north and south panels.

To avoid unnecessary further repetition, to
5 illustrate and explain the features and functions of the present invention device, reference shall be made to application to the (previously defined) model satellite, which is operated in a three-axis-stabilized, Earth-pointing, geosynchronous mode. (That is not to say that
10 application of the present invention device is limited to spacecraft that resemble the previously described model spacecraft and/or are operated in the corresponding mode. For example, the present invention device is also applicable to spin stabilized spacecraft with irregularly
15 shaped structures that are neither nadir pointed nor geosynchronous.)

Through each orbital revolution of a spacecraft like the model spacecraft, which in a preferred embodiment is
20 around the Earth, the Sun sequentially directly illuminates the east, zenith, west, and nadir main-body panels. While illuminated (or insolated) thus these main-body panels absorb incident solar energy and their temperatures increase, which significantly reduces their
25 net radiative cooling capability. If not countered by some means this can significantly limit the quantity of equipment (which dissipate heat into the spacecraft) that can be carried on board, and/or can result in undesirably elevated temperatures of associated spacecraft equipment.
30 The north and south panels, however, generally face deep space during the entire orbit and only directly receive solar illumination and solar energy at relatively low

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incidence angles on a seasonal basis. Because the direct input of solar energy into the north and south panels is relatively low to zero, these panels are the principal sites on spacecraft like the model spacecraft for the locations of thermal-energy radiator surfaces. The north panel is directly heated by the Sun for a duration of about 6 months (from about March 21st to about October 21st) at an incidence angle, defined as the angle between the panel plane and the sun vector, which seasonally increases from 0 degrees (when the sun vector is edge-on to the panel) to about 23.5 degrees followed by a decrease to 0 degrees again while the Sun is on the north side of the earth equator, i.e. during the northern spring and summer. The south panel is directly heated by the Sun for the remainder of the year, i.e. during the southern spring and summer, in a similar fashion and concomitantly with the north panel. These relatively low solar incidence angles favor use of the north and south panels for locating the principal thermal radiator surfaces of the spacecraft. At a maximum incidence angle of 23.5 degrees for the solar vector relative to the north and south panels the incident solar energy is approximately 40% of that for normal (perpendicular) incidence.

25

In the prior art numerous design practices have been employed to the surface treatment of the north and south panels in an effort to reduce the absorbed solar energy, thereby allowing more internal heat dissipation without raising the operational temperature level of the equipment that is thermally coupled to the panels. One example, optical surface reflectors (OSRs), which have a

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high ratio of thermal emissivity versus solar absorptivity, have been widely used as the surface treatment of spacecraft thermal radiators. However, the seasonal solar heating of the spacecraft through OSRs
5 still constitutes a significant amount of heat input to the spacecraft, which forces the spacecraft designer to lower the level of internal power dissipation to maintain an acceptable operating temperature for the spacecraft equipments. Solar energy absorbed by a spacecraft like
10 the model spacecraft through its north and south panels has two obvious undesirable impacts on the performance of the spacecraft.

(1) It reduces the allowable level of internal power
15 dissipation, which directly relates to the "value" of a spacecraft. The revenue from a spacecraft, especially a commercial communications spacecraft, is fundamentally limited by its capacity for power dissipation. A reduced allowable power dissipation level directly results in
20 lower potential for revenue generation, which reduces the value of the spacecraft.

(2) The operating temperatures of the internal
equipment are increased, and as a result the reliability
25 of those components may be reduced. The reliability also relates to the life of a spacecraft, which directly relates to its "value" as well.

If the undesired solar heating were to be reduced,
30 higher operational payload power would be allowable within the spacecraft and/or lower operating temperatures of the spacecraft equipments would be achieved.

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Therefore, by virtue of the present invention, the spacecraft could be operated at a higher efficiency, with higher reliability, and would thereby generate revenue at a faster rate, all of which improvements would increase its value.

There is another important factor that affects the capability of a thermal radiator surface to reject heat to deep space: the "effective" radiative view factor (ranging from 0 to 1) from that panel to deep space. The ideal radiative-view-factor enabling a panel to reject maximum heat into deep space is unity (1). A device or means situated between the radiator surface and deep space could block the radiator's view to deep space and thus reduce the heat-radiating capability of the radiator.

The sun ray blocker device of this invention is mounted on the spacecraft, for example conveniently attached to the solar array assembly/assemblies of the spacecraft and rotating therewith. Since the primary function of the sun ray blocker device used in this invention is to provide a significantly more benign thermal environment for the principal thermal radiator surfaces (or panels), basically by shading them, the spacecraft should have at least one such surface. In the case of three-axis-stabilized Earth-pointing geostationary spacecraft, for example, there are two principal thermal radiator surfaces - the north and south panels; and accordingly at least two separate sun ray blocker devices can be included, one to shade each of these panels. Thus, the sun ray blocker device in the

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present invention follows the movement of the Sun with respect to the thermal radiator panel(s) that it shades. In the case of a three-axis-stabilized Earth-pointing geostationary spacecraft, like the model spacecraft for example, the sun ray blocker device casts its shadow onto its associated thermal radiator surface, which is on either a north or a south panel, seasonally - through the six month long northern spring and summer in the case of the north panel, and through the six month long southern spring and summer in the case of the south panel. The (counter-productive) reduction in the radiation-view-factor of the thermal radiator surface caused by the presence of the associated present invention device is small; and the net effect of this reduction combined with the (beneficial) shading of the panel is a great improvement in the radiative efficiency of the radiator surface.

In addition to the foregoing, some of the considerations, advantages and parameters for the present invention device are as follows (others will become self-evident from the subsequent discussion of the FIGURES):

Variety in the operational form and size of the sun ray blocker device is permissible provided that its sun blocker panel follows the movement of the Sun with respect to the spacecraft, and it blocks the Sun's rays by casting a shadow onto the spacecraft main body at appropriate times, and it produces close to the minimum reduction in the effective radiative view factor to deep space of the thermal radiator that it shields, and it

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satisfies other system requirements of the spacecraft
(for example clear field of view requirements).

5 The material and/or the construction of the sun
blocker panel of the sun ray blocker device is preferably
highly thermally insulating between its sun and anti-sun
sides in order to provide the greatest practical
effective radiative view factor and radiative efficiency
of the radiator-surface shielded by the sun blocker
10 panel.

In its fully deployed configuration the sun blocker
panel may be mounted through a wide range of orientations
relative to the radiator surface that it shields (for
15 example, the angle 501 in FIGURE 12a below does not have
to be 90 degrees i.e. a right angle) as long as it casts
shadow providing adequate coverage of the associated
thermal radiator surface(s) on the spacecraft.

20 The ideal width of the sun blocker panel is greater
than either the width or the length of the radiator
surface that it shields. However, the dimensions of the
sun blocker panel may be limited by other constraints.
For example, in the launch configuration the folded
25 dimensions of the sun blocker panel may be limited by
launch-envelope constraints, i.e. the size of the volume
allowed for the spacecraft by the launch vehicle during
launch. Therefore, it may be necessary to make the sun
ray blocker panel deployable to enable it to be folded
30 for launch and deployed in orbit. This can be achieved by
hinged deployment, slide extension, pre-offset or any
other means to increase the width of the sun blocker

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panel (see FIGURES 16a, b and c, and 17a, b and c discussed below).

5 The mechanisms for extending, deploying, and supporting the sun blocker panel may involve various techniques and devices that are well known in the current state of the art of the design of mechanisms for spacecraft. For example the techniques and devices employed could involve mechanisms constructed from well known device types such as: hinges, flaps, slides, spring
10 motors, wax motors, detentes, cable/bolt cutters, split nut releases, pin pullers, hook and pin releases, etc. Alternatively, so-called "active" devices such as electrical motors may be used at the discretion of the spacecraft designer. For example, one or more electrical
15 motor (for example a stepper drive motor) could be employed to produce the motions resulting in extension (and possibly also retraction) of the sun blocker panel. Such active control could be utilized to facilitate
20 certain operations of the spacecraft, for example station-keeping and attitude control operations for which displacing the sun blocker panel from the exhaust plume fields of rocket thrusters would be beneficial.

25 The present invention device is applicable to spacecraft other than those spacecraft, like the model spacecraft for example, which operate in the low-inclination or equatorial orbits that have been described thus far herein. It is applicable to the broad class of
30 spacecraft for which the solar illumination (insolation) is incident at low angles relative to the planes of the surface(s) of their thermal-radiator surface(s).

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A certain subset of spacecraft belonging to the set of spacecraft that are well known in the space industry as "sun synchronous" fulfill this requirement for low solar incidence angles on at least one thermal radiator surface; and the present invention is applicable to them. Within this subset of sun synchronous spacecraft is an even smaller but well known subset comprised of those spacecraft that operate in orbits with low orbit-Sun angles and in which the thermal radiator surfaces are utilized while oriented close to parallel to the orbit plane. A sun ray blocker device according to this invention is applicable to those spacecraft, to provide them with a shaded, benign, and desirable thermal environment for their thermal-radiator surfaces basically by protecting them against direct solar heating. Note, however, that when the angle of incidence of direct sunlight on the thermal radiator surface is zero the sun ray blocker device is unnecessary.

20

Heretofore the structural configuration and orientation of spacecraft to which the current invention device is applicable have mainly been described with reference to three-axis-stabilized Earth-pointing spacecraft for operating in low inclination or equatorial orbits, like the model spacecraft for example. The fundamental difference between those preceding descriptions and the structural configurations and orientations of the sun synchronous spacecraft to which the current invention device is applicable stems from the orientation of the orbit with respect to the axis of rotation of the planet. Within the space industry, sun

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synchronous orbits are widely referred to as being "polar", since the orbit plane of a sun synchronous orbit, around Earth and Mars at least, lies within several degrees of the axis of rotation of the planet; and therefore nominally includes the planetary poles. Therefore, for the aforementioned particular subset of sun synchronous spacecraft to which the current invention device is applicable, the panels and the radiator surfaces on them that are thermally protected by the current invention device are generally not, strictly speaking, "north" and "south" panels. However, herein the terms "north" and "south" are occasionally used for convenience to indicate the panels that are thermally protected by the sun blocker panel on spacecraft in sun synchronous orbits as well as on spacecraft like the model spacecraft, for example, in (nominally) equatorial orbits. The rationale is that in the particular, suitable, well known, and currently populous, aforementioned, subset of sun synchronous spacecraft the planes of thermal radiator panels shielded by the present invention device are also approximately perpendicular to the axis of the orbit (as for spacecraft like the model spacecraft in its orbital configuration and orientation). For both these types of spacecraft we could instead meaningfully refer to the protected panels and radiator surfaces as "pitch-axis" or "orbit normal" panels and surfaces, because the pitch axis of the spacecraft (which is parallel to the orbit normal) is nominally/approximately perpendicular to them and thereby defines their orientation.

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Depending upon the requirements of the propulsion subsystem and/or the attitude control subsystem of the spacecraft, the spacecraft designer may elect to provide only one sun ray blocker device, i.e. on only one of the two sides of the spacecraft that face approximately along the pitch axis (e.g. on the north or the south panel for the model spacecraft). In any particular application there may be a preference for one side of the spacecraft over the opposite side because of other system requirements. For example, in a potential embodiment of the present invention device on a particular current design of geostationary spacecraft, the south side is preferred because of field of view requirements for attitude-control thrusters on the north side.

Again, if the spacecraft designer elects to do so, solar cells can be mounted onto the external surfaces of the sun blocker panel to provide additional power to the spacecraft.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention should be more fully understood when the specification herein is taken in conjunction with the drawings appended hereto showing exemplary embodiments of the invention wherein:

FIGURE 1 is a simplified perspective view of a prior art three axis stabilized Earth-pointing geosynchronous spacecraft;

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FIGURE 2 shows an east-panel based view of the prior art spacecraft illustrated in FIGURE 1 orbiting in a low inclination or an equatorial orbit;

5 FIGURE 3a shows a north-panel based, top view of the prior art spacecraft illustrated in FIGURE 1 orbiting about the Earth at different times of the day, and FIGURE 3b illustrates orbit-plane based views of that spacecraft at its noon, 6 a.m., and midnight positions and also
10 establishes sun angles for different seasons of the year;

FIGURES 4a and 4b show the variation in the solar incidence angle on the north and south panels, respectively, of the prior art spacecraft illustrated in
15 FIGURE 1 orbiting Earth, through one calendar year;

FIGURE 5 illustrates a perspective view of a spacecraft configuration according to the present invention, based on the prior art spacecraft illustrated
20 in FIGURE 1;

FIGURES 6a, 6b and 6c illustrate top views of a present invention arrangement as applied to the prior art spacecraft illustrated in FIGURE 1. The views shown are
25 simultaneously parallel to both the orbit-plane and the plane of the solar cell panels and the sun blocker panels of the sun ray blocker device. Hereinafter this view direction is also referred to as "top view". FIGURES 6a, 6b and 6c show that as the spacecraft revolves around the
30 orbit the earth panel always faces the Earth, and the cell-side of the solar array panels together with the

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front (sunward) sides of the sun blocker panels of the sun ray blocker devices always face the Sun;

5 FIGURES 7, 8 and 9 illustrate top views of present invention devices utilizing different attachment arrangements;

10 FIGURES 10a, 10b and 10c illustrate portions of top views of one of the solar array assemblies of a prior art spacecraft before, during, and after its deployment;

15 FIGURES 11a, 11b, 11c, 12a, and 12b show, in top view, aspects of the deployment and the function of present invention devices as applied to the prior art spacecraft shown in FIGURES 10a, 10b, and 10c;

20 FIGURES 13 and 14a show partial top views of two alternative present invention devices; and FIGURE 14b shows a partial back (anti-sun) side view of the arrangement shown in FIGURE 14a;

25 FIGURES 15a and 15b show partial top views of an alternative present invention device in its fully deployed and partially deployed configurations, respectively;

30 FIGURES 16a, b, and c show a view of an alternative present-invention device from the front (sunward) direction with the sun blocker panel fully deployed, and two views from a direction orthogonal to both the front view and the (previously defined) top view directions

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with the sun blocker panel folded and deployed,
respectively;

FIGURES 17a, b, and c show a different alternative
5 present-invention device in the same views and deployed
states as those shown in FIGURES 16a, b, and c;

FIGURE 18 shows a further embodiment of the
invention;

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FIGURE 19 shows another embodiment of the invention;

FIGURE 20 shows another embodiment of the invention;

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FIGURES 21 to 24 and 26 show another embodiment of
the invention;

FIGURE 25 shows details of the embodiments of
FIGURES 21 and 24 and 26;

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FIGURES 27 to 30 show another embodiment of the
invention; and

FIGURES 31 and 32 illustrate alternative shapes for
25 sun blocker panels used in the present invention.

Referring now to FIGURE 1, there is shown an oblique
view of a fully deployed (i.e. fully unfolded from its
launch configuration) spacecraft (or satellite) 1, like
30 the previously described model spacecraft for example,
which is represented by a main body 10 which contains six
external panels: 11, 12, 13, 14, 15 and 16, a group of

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antenna reflectors 20, 21, 22 and 23, and two solar array assemblies, consisting of two solar arrays (one or more solar cell panel) 100 and 101 and their supports 100a and 101a by which they are connected to the main body 10, which are extended northward and southward from the main body out of the north and south panels 11 and 12, respectively. The number of antenna reflectors is driven by the need of the telecommunications application and is a matter of design. In this example, four reflectors are shown and are represented by two deployable large reflectors 20 and 21 mounted on east and west panels 15 and 16, respectively. Two non-deployable reflectors 22 and 23 are mounted on nadir panel 14. While orbiting in a low inclination orbit about Earth, the spacecraft is controlled in such a way that the earth or nadir panel 14 is pointing in the general direction of the center of the Earth, thus allowing the antenna reflectors to perform telecommunications functions with Earth. Opposite to the earth panel 14 is the zenith panel 13.

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The solar arrays 100 and 101 may contain multiple panel elements (typically two to eight or more on each side - a four panel-element example is shown in FIGURE 1) or may contain as few as one panel element. However, usually solar arrays that are comprised of multiple solar cell panels are utilized, in order to provide sufficient electrical power for the spacecraft's use. The size and number of the solar cell panels is driven by mission power requirements, and is constrained by, among other factors, the capability of the attitude control subsystem to maintain pointing stability and also by the capability of the thermal control subsystem to manage the heat

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dissipated on board the spacecraft. Once the size and number of the panel elements is defined, generally it is desired to maximize the electrical power generated by the solar cells which are mounted on one side of the array panels by facing the cell side of the array toward the Sun as directly and as long and continuously as possible. With spacecraft main body 10 maintaining its earth panel 14 pointing to the Earth continuously, the line between the spacecraft and the Sun will cone around the north-south axis of a spacecraft like the model spacecraft once every orbit, making the Sun appear to circle about the main body 10 as it does so. In order to maintain both solar arrays of a spacecraft like the model spacecraft pointing directly to the Sun they are driven by motor systems which rotate the arrays about the north-south axis, as indicated by the arrow R in FIGURE 5 with respect to the main body 10 at a speed such that the cell side of the array always faces the Sun while the spacecraft orbits the Earth, i.e. the solar arrays rotate about the north-south axis sun synchronously with the Sun to achieve optimum sun exposure for maximum power generation.

Reference is made to FIGURE 2, a top view of prior art spacecraft or satellite 1 of FIGURE 1, wherein the aforesaid seasonal exposures are illustrated. (Parts identical or very similar to those in FIGURE 1 are identically numbered throughout the FIGURES herein and are not all repeated, to reduce redundancy. This applies to all of the following FIGURES that illustrate the same spacecraft or the same parts or components, or ones very similar.) The north panel 11 and the south panel 12

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(FIGURES 1 and 2) are maintained oriented parallel to the orbital plane of the satellite, which is co-planar or nearly co-planar with the equatorial plane of the Earth. While the spacecraft is orbiting the Earth, these panels
5 (11 and 12) will not receive daily solar input like the other panels (earth panel 14, zenith panel 13, east panel 15 and west panel 16). Those two panels 11 and 12, however, will be subjected to direct solar heating on a seasonal basis, at incidence angles which will peak at
10 23.5 degree at the northern summer- and northern winter-solstices respectively, as shown.

FIGURE 3a shows a north-based top view of a spacecraft 1 orbiting Earth at different local times of day and illustrates the constancy with which the nadir
15 panel 14 faces Earth 300 throughout the orbital revolutions. (The solar cell panels are shown edge-on out of the paper.)

FIGURE 3b shows a partial side view of the spacecraft 1 of FIGURES 1 and 2 at midnight, 6 a.m., and noon orbital positions, and also the approximate sun
20 angles at the northern summer and northern winter solstices at midnight and noon.

FIGURES 4a and 4b show the profile of the solar incidence angle on the north and south panels, respectively, such as panels 11 and 12 of spacecraft 1
25 shown in FIGURE 1, for one calendar year.

30 It can be seen from FIGURES 4a and b that sunlight is incident on each of the north panel and south panel

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for a portion of the calendar year. These periods are nominally 21 March through 21 September for the north panel, and 21 September through 21 March for the south panel. Therefore, the sun ray blocker devices of the
5 current invention perform their shading functions for their respective radiator panels for those periods only.

FIGURE 5 illustrates one preferred embodiment of the current invention, which eliminates or greatly reduces
10 the seasonal solar input on the north and south panels 11 and 12, thus providing more efficient thermal radiators for the spacecraft.

In this present invention embodiment, the sun ray
15 blocker devices are comprised of two sun blocker panels 111 and 112 and mounting, supporting, and deployment mechanisms by means of which the blocker panels are integrated with and deployed with the structures and mechanisms that support and cause the solar array to
20 rotate. The radiators on the north and south panels 11 and 12 have dedicated sun ray blocker devices 111 and 112 attached to the north and south array assemblies 100 and 101, respectively, as shown in FIGURE 5. After the thus modified spacecraft 1 has been launched into the
25 operational orbit and its appendages have been fully deployed, the sun blocker panels 111 and 112 will achieve their final positions in front of the cell side of the solar arrays with their surfaces more or less parallel to the plane of the solar arrays. The south blocker device
30 112 is positioned such that during the time between the northern autumnal and northern spring equinoxes, when otherwise there would exist a potential for solar heating

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of the south panel 12, the south blocker device 112 will cast a shadow over the south panel 12 thereby eliminating the potential for such solar heating. The north blocker device 111 performs a similar function relative to the north panel 11 during the time between the northern spring and northern autumnal equinoxes. When the solar array assemblies 100 and 101 are maintained directly sun pointed, by virtue of their being rotated, the sun blocker devices will likewise be maintained directly sun pointed and thereby interposed between the Sun and the north and south panels that they shade.

The materials used for the sun blocker panels 111 and 112 are selected to minimize the heat transferred from their sun facing surfaces 111a and 112a to their anti-sunward surfaces 111b and 112b. This may be achieved by including insulating material(s) and constructions in the composition of the sun blocker panels. For example, the panels may include known thermally insulating materials and assemblies of materials, such as multi-layer insulation (MLI) blankets which utilize layered films of metallized Mylar separated by fabric netting. These materials and constructions are well known in the space industry and have typical heat resistance values of 0.007 to 0.01 Watt/deg.C/sq.in. The sun blocker panels of the present invention device will generally experience a sizable temperature difference, for example possibly greater than 100 degree C, between surface 111a and surface 111b and between surface 112a and surface 112b when the satellite is in its normal orientation in the mission orbit, except when the spacecraft is passing through the Earth's shadow.

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To obtain the maximum sun blocking effect, the panels of the sun ray blocker devices 111 and 112 are configured (sized, oriented, and positioned) in such a way that at the summer and winter solstices, when the Sun is about 23.5 degree from the orbit plane, the sun blocker devices will cast shadows that entirely cover the radiator surfaces on their respective thermal radiator surfaces on the spacecraft panels 11 and 12.

Accordingly, if the radiator surfaces are rectangular the shadows must be at least as wide as the diagonals of the rectangles.

FIGURES 6a, 6b and 6c show top partial views of a present invention arrangement as the spacecraft orbits Earth and the main body 10 is rotated at the orbital rate so that the earth panel 14 always faces Earth, and the sun blocker panels 111 and 112 always face the Sun (which is at the left in the FIGURES). These FIGURES are drawn in the inertial frame of reference of the solar array assemblies 100 and 101. Thus, if one were to stand on either of the solar array assemblies 101 and 102 one would see main body 10 rotate one revolution per orbital revolution around the Earth.

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FIGURE 7 is a top partial section view showing more details of a present invention spacecraft. In this context the phrase "top view" denotes a view parallel to the planes of the sun blocker panels 111 and 112 and also parallel to the orbit plane. Note that in Figure 7 through Figure 15b various examples of embodiments of the present invention are depicted together with generic

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partial views of a spacecraft main body and a solar array assembly (labeled 400 and 408, respectively, later in FIGURES 10 and FIGURES 11). Additionally, FIGURES 8 and 9 show alternative embodiment arrangements in top partial section views.

In FIGURE 7, the spacecraft has main body 10, north panel 11, and solar cell panel support 223 with attached solar cell panel 225. In this case, there is a connecting solar array boom-and-yoke 219 and hinges at hinge points 221 and 227. Together this solar cell panel support 223, a solar cell panel 225, a solar array boom-and-yoke 219, and the hinges at hinge points 221 and 227 comprise part of a solar array assembly. The solar array boom-and-yoke 219 fold forwardly against north panel 11 and the solar cell panel support 223 together with the solar cell panel 225 folds down at hinge point 227 in an accordion-like fashion for launching. During launch, ascent, and orbit achievement the solar array assembly is in its folded-closed configuration. After achievement of the mission orbit it is electro-mechanically and/or mechanically deployed (unfolded) to allow the solar cells to be maintained directly sun-pointed. Attached to solar cell panel support 223 is a two-section connecting arm having a short inner portion 209 and an outer portion 207 connected by hinge(s) at hinge point 215. The anti-sunward side 111b of sun blocker panel 111 is connected to outer arm portion 207 by hinge(s) at hinge point 203. Optional solar cells 201 are functionally positioned on the sunward surface 111a of the sun blocker panel 111. Hinge points 203 and 215 provide for folding of the solar blocker panel 111 and its hinged arm 207 against the

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solar cell panel 225 in a compact and stiff configuration suitable for launch and subsequent deployment. The electromechanical and/or mechanical designs and methods for deploying (opening) and closing solar array assemblies are commonly used in contemporary spacecraft. The same or similar mechanisms are used to deploy the sun ray blocker devices of the present invention. These mechanisms and methods for deployment and closing are well within the skills of the artisan.

10

In FIGURE 7, there is an imaginary plane 250 extending off the surface of north panel 11. In its deployed configuration the sun blocker panel 111 may touch or extend through this imaginary surface, and consequently may provide additional shading for the earth, west, zenith and east panels as they rotate with respect to the Sun.

FIGURE 8 shows an alternative embodiment where sun ray blocker device 271 does not intersect imaginary plane 250. Further, it has a single connecting arm 205 with hinge points 203 and 217 at opposite ends to form an assembly and is connected directly to the substrate of solar cell panel 225. It may be folded and stowed for launch and deployed or unfolded in orbit in a similar way to the sun ray blocker device in FIGURE 7. In FIGURES 7 and 8, the sun ray blocker devices cast their shadows over the major part of the outer surface of north panel 11 and, in these embodiments, completely shadow that surface during the times when otherwise they would be exposed to the Sun. Further, the solar cells 201 may be

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included to produce additional solar power for the spacecraft.

In FIGURE 9, identical parts to FIGURES 7 and 8 are identically numbered. Sun ray blocker device 301 is connected directly to solar cell panel support 223 by hinge(s) at hinge point 309 so as to fold over up-close against solar cell panel 225 in the launch configuration. In this embodiment, sun ray blocker device 301 is not parallel to the solar array, yet still effectively shades north panel 11.

FIGURES 10a, 10b and 10c depict a typical prior art sequence of deployment of a solar array assembly, which is part of the transformation of the spacecraft from its launch configuration to its configuration for normal operations in orbit. For simplification in this document, only one (the north) solar array assembly is shown in the FIGURES. These particular FIGURES show a satellite with a main body 400, and a solar array assembly 408 comprised of four solar cell panels, with solar cell surfaces 400a, mounted on solar cell panel supports 408 which are interconnected by hinges at three hinge points 403, 404, and 405 and connected to the main body 400 by a single boom 419 and hinge(s) at hinge points 401 and 402. FIGURE 10a depicts the solar array assembly folded and stowed for launch. FIGURE 10b depicts it in the process of being deployed (unfolded). Figure 10c depicts its fully deployed state. If a multiple-arm boom design is desired by the spacecraft designer, various embodiments can be designed to satisfy

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performance requirements using greater numbers of arms and hinge points.

FIGURES 11a, 11b and 11c illustrate the deployment sequence of one possible design embodying the present invention. Components in FIGURES 11a, 11b, and 11c that are identical to components in FIGURES 10a, 10b, and 10c are numbered identically to their identical parts. In addition to the prior art solar array assembly that was previously depicted in FIGURES 10a, 10b and 10c, FIGURES 11a, 11b, and 11c also depict the present invention sun blocker panel 411 connected to the solar array boom 419 by an arm 430 and hinges at hinge points 406 and 407. Alternatively, by design the sun blocker panel 411 could be hingedly attached via the arm 430 to a convenient different location on the solar array assembly. FIGURE 11a depicts the solar array assembly and the sun ray blocker device folded and stowed for launch, FIGURE 11b shows them partially deployed (unfolded). FIGURE 11c depicts their fully deployed state. FIGURES 12a and 12b show sun blocker panels which are not parallel to the plane containing the solar cell panels yet which still provide proper shading of the north or south panel. Components in FIGURES 12a and 12b and subsequent figures that are identical to components that appear in previous figures are numbered identically with their corresponding or very similar components or are left un-numbered to avoid unnecessary repetition. Alternatively, by design the sun blocker panel 111 could be hingedly attached via the arm 430 to a convenient different location on the solar array assembly.

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FIGURE 13 depicts yet another alternative embodiment of the present invention. The sun blocker panel 511 is connected to the solar array boom 219 by hinge(s) at hinge point 507 for its stowing folded and subsequent deployment.

FIGURES 14a and b show an arrangement similar to that in FIGURE 13, with identical parts identically numbered, however, more hinges at hinge points 606 and 607 are used with blocker panel 611 as required by design for folding the panels prior to deployment.

FIGURE 14b represents a partial view of the anti-sun side of the spacecraft looking toward the Sun (i.e. a side view relative to the top view shown in Figure 14a).

FIGURES 15a and 15b show one embodiment in which sun blocker panel 811 utilizes separate active motors 306 and 307 which are used to actively deploy and/or retract the sun ray blocker device. This arrangement allows satellite operators to use deployment motors that are separate from the solar panel deployment motors so as to permit them to retract the sun blocker panels to prevent their interference, if any, in satellite operations such as in the use of propulsion systems during spacecraft performance of station keeping or attitude control maneuvers.

In some spacecraft designs the required size (dimensions and/or area) of a sun blocker panel in its fully deployed configuration may exceed the constraints of its "launch envelope" i.e. the constraints of the

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maximum-allowable space allocated to the sun ray blocker device in the launch configuration of the spacecraft when the solar array and the sun ray blocker device are in their launch configuration. Therefore, for compatibility with the constraints of the size of the corresponding launch envelope it may be necessary for the sun blocker panel of the sun ray blocker device to be comprised of several (i.e. more than one) pieces, instead of being one single integral piece, which are folded together in the launch configuration and are subsequently deployed (unfolded) in orbit to form effectively one continuous sun blocker panel. FIGURES 16a, 16b and 16c, and FIGURES 17a, 17b and 17c, respectively depict two examples from the many possible designs for sun blocker panels which fold and deploy. Parts a, b, and c of the FIGURES 16 and 17 show each of the two designs in a view from the front (Sun) direction with the sun blocker panel fully deployed, and two views from a direction orthogonal to both the front view and the top view directions with the sun blocker panel folded and deployed, respectively. (As defined earlier herein the phrase "top view" denotes a view that is simultaneously parallel to the plane of the sun blocker panels 921 or 951 and the orbit plane.) This allows the sun ray blocker device to increase its dimensions using hinge(s) and/or strut(s) and/or flap(s) etc. at hinge points 925 and 927 or a slide-out design. Referring collectively to all FIGURES 16, sun blocker panel 921 has a center section 923 with hinge(s) and/or strut(s) and/or flap(s) etc. at hinge points 925 and 927 and outer, swing up panels 929 and 931 which may be designed to deploy (swing up) automatically. In all FIGURES 17, sun blocker panel 951 has main section 953

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with slide-out extensions 955 and 957 that may be designed to deploy (slide out) automatically. (Automatic hinging and automatic sliding or telescoping is well within the purview of the artisan in the spacecraft industry and need not be further elaborated upon herein.)

The embodiments of the present invention device illustrated in FIGURES 18 through FIGURE 30 are as generally applicable as the other embodiments described herein. However, they also function efficiently in cases where a sun blocker device cannot be attached to an axle located near the center (1811, 2123, 2722) of an associated thermal radiator surface (1804, 2121, 2721).

One such case is that in which the axis of rotation (1803, 2131, 2701) of a solar array assembly extends outward from the associated thermal radiator surface (1804, 2121, 2721) at a location that is significantly offset from the center (1811, 2123, 2722) of the thermal radiator surface. In that case, designs with an attachment arm of fixed length between the sun blocker panel and the solar array axis could be unsuitable, because the motion of the sun blocker panel about the center of the thermal radiator surface would be eccentric.

Another such case is that in which there are stay-out zones inboard of the periphery of the associated thermal radiator surface - through which objects such as a supporting boom (for example for a sun blocker panel) are not allowed to pass. This could be the case, for example, when certain attitude- or orbit- control

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thrusters (1810) are also located on the panel upon which the thermal radiator surface (1804) is located.

5 The arrangements illustrated in FIGURES 18 through
FIGURE 30 may be employed to overcome these constraints,
whilst still maintaining a sun blocker panel at a
substantially uniform distance from the center of the
associated thermal radiator surface. Selection between
the embodiments shown in FIGURES 18-30 for any particular
10 application may involve trade-offs between many
additional performance-requirements of the spacecraft-
system, including for example: mass, strength, stiffness,
flatness, circularity, simplicity, and reliability.

15 Figure 18 shows an embodiment of a sun blocker
device in which the sun blocker panel 1800 is mounted on
a carriage 1801 with wheel-sets or bearing-sets 1808 and
1830 by means of an attachment arm 1805 in which the
carriage may be driven around a closed rail 1802, the
20 carriage 1801 being attached to the rail 1802 by rolling
or sliding means that also react against and thereby
limit rotations of the carriage 1801 (and thereby the sun
blocker panel) about axes passing through the points of
contact of the carriage and the rail. In one of many
25 potential embodiments, for example, this may be achieved
using wheel or bearing sets 1808, 1830 that are
adequately spaced both along-track and cross-track on
both sides of the rail 1802, and which are also cambered
at an adequate angle to the plane of the baseplate.
30 Attached to the carriage is at least one generally-radial
boom or strut 1805, an outer end of which is attached to
the sun blocker panel at hinge point 1812 and an inner

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end of which is attached to the carriage 1801 at hinge-point 1813, and the carriage is rollingly or slidingly mounted on the rail 1802 by the wheels or bearings 1808 and 1830. At least one of these wheels 1830 or bearings is provided with a motor to drive the carriage along the rail 1802, for example by friction, or by the engagement of a toothed wheel or a worm-drive in a rack. Electrical power may be supplied to the motor, via brushes for example. The attachment arm 1805 and the sun blocker panel 1800 can be folded at the hinge points 1812 and 1813 to achieve a stowed configuration of the sun blocker device for launch, during which the folded device may be temporarily caged securely for proper management of launch-induced dynamic environments and loads. The sun blocker panel may be further folded for launch as illustrated in FIGURES 16 and 17. Following launch the attachment arm 1805 and the sun blocker panel 1800 can be deployed for subsequent operation in orbit, including sun-tracking travel around rail 1802. It will be appreciated that the rail 1802 need not be circular as shown in FIGURE 18, but in the case of a significantly rectangular thermal radiator surface, for example, the rail could be elliptical and in either case may be diverted to avoid obstacles mounted on the spacecraft.

25

Alternatively, as illustrated in FIGURE 19 the attachment arm 1805 could be mounted on a solid rotatable wheel instead of on a carriage and rail. In the embodiment illustrated in FIGURE 19 the wheel is a ring or annulus 1902 floating in circumferentially located bearing-sets 1903 and controlled and driven by a motor 1930 mounted on the baseplate under 1804.

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In a similar alternative embodiment, illustrated in FIGURE 20, a carriage 2001, similar to that provided in the embodiment illustrated in FIGURE 18, is provided; but
5 in this embodiment the carriage 2001 is driven around a closed rail 2002 not by a motorized wheel, but by an endless belt 2003, chain, or cable attached to the carriage 2001, the belt being driven by a motor 2030 that is mounted to the baseplate under 1804 and which engages
10 the belt 2003, chain, or cord. A tensioning device 2040 is also provided to engage the belt 2003 and tension the belt while not impeding the passage of the carriage around the rail 2002. Again, as in the embodiment illustrated in FIGURE 18 the rail 2002 need not be
15 circular.

Figures 21 through 30 illustrate embodiments in which a sun blocker panel is mounted on the spacecraft via an attachment arm from an axis 2131, 2701 that is
20 offset from the center 2123, 2722 of an associated thermal radiator surface. The axis 2131, 2701 could be concentric with or identical to the axis of rotation of a solar array assembly.

25 Figures 21 through 26 illustrate an alternative embodiment in which a sun blocker panel 2100 is attached to an axle at axis 2131. The axle may be either concentric with or identical to an axle of a solar array assembly. The sun blocker panel is attached to the axle
30 by an articulated attachment arm 2130 that included three articulated portions 2132, 2134, 2137.

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The inner end of the inner-portion 2132 is fixed radially to the axle at axis 2131. The middle-portion 2134 is pivoted at its inner end to inner-portion 2132 at pivot-point 2133, and the outer end of middle-portion 2134 is pivoted to the inner end of outer-portion 2137 at pivot point 2135. At its outer end the outer-portion is attached to the sun blocker panel at hinge point 2138 and near its inner end the outer-portion is hinged at hinge point 2136 to allow folding and stowing for launch followed by deployment in orbit.

As depicted in FIGURE 21 through FIGURE 26 the inner-portion 2132 and the outer portion 2137 of the attachment arm 2130 turn anti-clockwise at the same rate, the outer-portion 2137 carrying the sun blocker panel with it, whereas the middle portion 2134 rotates clockwise at the same rate.

The length of the inner-portion 2132 is approximately equal to the offset of the axis of rotation 2131 from the center 2123 of the thermal radiator surface. In principle the length of the middle-portion 2134 may be longer or shorter than the length of the inner portion 2132. However, in the case that the axis of rotation 2131 is occupied by an obstruction such as the axle of a solar array assembly then the middle-portion 2134 must be shorter than the inner-portion 2132 for clearance of the solar array axle at axis 2131, as can be seen in FIGURE 23 in which the attachment arm 2130 is approaching its closest to the axle at axis 2131.

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By articulating the articulated portions through rotation of the arm 2130 about the axis of rotation 2131 the sun blocker panel can be maintained at a substantially constant distance from the center of the associated thermal radiator surface 2121, to describe a substantially circular path 2140 around the spacecraft. It will be evident that in the case of a thermal radiator surface that is significantly far from being radially symmetric the length of the articulated portions of arm 2130 could be adapted to achieve a wide range of desired paths around the thermal radiator surface.

As shown in FIGURE 21, the articulated portions 2132, 2134, 2137 are arranged to the full reach of attachment arm 2130 in a straight line when the sun blocker panel is passing a side of the thermal radiator surface furthest from the axis of rotation 2131. As shown in FIGURES 22 and 23 the attachment arm 2130 has an effective length equal to the sum of the lengths of an outer 2137 and an inner 2132 articulated portion when the sun blocker panel 2100 is at an intermediate distance from the axis of rotation 2131. As shown in FIGURE 23, the effective length of the attachment arm 2130 is at its minimum when the sun blocker panel is at its closest to the axis of rotation 2131, at which point its length is equal to the sum of the lengths of the inner 2132 and outer 2137 portions less twice the length of the middle-portion.

The inner articulated portion 2132 of the attachment arm 2130 rotates about axis 2131. The means of attachment of the inner articulated portion 2132 may be

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independent of a solar array axle along axis 2131, the inner portion 2132 then being mounted to a concentric tubular axis around a central solar array axle. Alternatively, the inner articulated portion may be fixed
5 solidly to a solar array axle along axis 2131.

In the illustrated embodiment, for a geostationary spacecraft for example the inner and outer articulated portions rotate anti-clockwise at one revolution per day,
10 and the middle articulated portion rotates clockwise at one revolution per day. This rotational relationship may be achieved by diverse means, such as: separate motorized pivots at pivot points 2131, 2133, and 2135; or by a system of belt-linked pulley wheels at pivot points 2131,
15 2133 and 2135, driven by a single motor or by an axle along axis 2131.

The articulated portions 2132, 2134, and 2137 may be sprung together, so that in a failure mode the attachment
20 arm 2130 automatically extends to its greatest length. In that case, any failed pivot points can be made to fail free, for example using commandable frangible-links in the associated pulley wheels or drive motor, allowing spring-driven extension of the arm 2130.

25
FIGURES 25 and 26 illustrate a means of articulating the articulated portions 2132, 2134, 2137 with respect to each other, utilizing a driving force from a solar array axle at axis of rotation 2131. A cylinder 2501 is
30 provided, mounted co-axial with the solar array axle at axis 2131 but fixed to a base panel 2121. The inner articulated member 2132 is fixed to the solar array boom

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at axis 2131 so that the inner articulated member 2132 rotates at the same rate as the solar array boom at axis 2131. A middle articulated portion 2134 is pivotally fixed to an outer end of the inner articulated portion 2132 at a pivot point 2133 and a pulley wheel 2502 of the same diameter as cylinder 2501 is fixed to an inner end of the middle articulated portion 2134. A toothed belt 2506 is looped around the cylinder 2501 and the pulley wheel 2502 so that as the solar array shaft 2131 and the inner articulated portion 2132 rotate anti-clockwise in a direction of the arrow 2507, the toothed belt 2506 causes the pulley wheel 2502 and the middle articulated portion 2134 to counter-rotate at the same rate in the direction of arrow 2508.

15

As shown in FIGURE 26, a second equal sized pulley wheel 2601 is fixed to an outer end of the inner articulated portion 2132 on a side of the inner articulated portion 2132 opposite to that on which the cylinder 2501 is fixed to base panel 2121, and a third equal sized pulley wheel 2602 is fixed to an inner end of an outer articulated portion, such that the third pulley wheel 2602 and the outer articulated portion 2137 are together pivotally attached to the outer end of the middle articulated portion 2134. A second toothed belt 2603 loops around the second pulley wheel 2601 and the third pulley wheel 2602 so that as the middle articulated portion 2134 rotates in the direction of arrow 2508 the toothed belt 2603 causes the outer articulated portion 2137 and the third pulley wheel 2602 to counter-rotate at the same rate in the direction of arrow 2604. Thus, the outer articulated portion 2137 rotates in the same sense

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as the inner articulated portion 2132 whereas the middle articulated portion 2134 counter-rotates.

In a further embodiment illustrated in FIGURES 27 through 30, a sun blocker panel 2700 is attached to an axle 2701 of a solar cell array by means of a scissor attachment arm 2730. The scissor arm is comprised of a first articulated arm 2704, 2708 and a second articulated arm 2705, 2709, comprised of inner articulated portions 2704, 2705 and outer articulated portions 2708, 2709 respectively. The inner articulated portions are connected by hinges at hinge points 2702, 2703 to the solar array boom 2701 respectively and the outer ends of the outer articulated portions 2708, 2709 are connected by hinges 2710, 2711 to the sun blocker panel 2700 such that when the articulated arms are extended to the full length they are still not parallel to avoid their locking up. A lanyard 2712 is located in between the articulated arms 2704, 2708 and 2705, 2709 and extends between the sun blocker panel 2700 and the solar array axle 2701. The inner articulated portions 2704, 2705 and the outer articulated portions 2708, 2709 are sprung at hinge points 2706 and 2707 so as to automatically extend the articulated arms 2704, 2708 and 2705, 2709 to their full extent as limited by the lanyard control. The articulated arms 2704, 2708 and 2705, 2709 thereby form a parallelogram, the shape of which may be controlled by retracting or deploying the lanyard 2712. Alternatively the shape of the parallelogram could be controlled by motorized hinges, or alternatively by a retractable and deployable lanyard between hinge points 2706 and 2707 with sprung hinges 2702, 2703, 2710 and 2711 instead of

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at 2706 and 2707. In the embodiment of the invention illustrated in FIGURES 21 through 24, the distance of the sun blocker panel 2700 from the solar array boom 2701 can be varied as the sun blocker panel 2700 rotates about the solar array boom 2701 to maintain the sun blocker panel at a constant distance from the spacecraft as illustrated by the path 2712.

The embodiments described in FIGURES 18 through 20 have the advantage that the attachment arm does not obscure thrusters 1810 present on the face of the spacecraft, that the sun blocker panel shades.

A sun blocker panel 3100, 3200 is not necessarily rectangular in shape. As shown in FIGURE 31, the sun blocker panel 3100 has trapezoidal first-and second-extensions 3101, 3102 hingedly attached to a main body 3103 of a sun blocker panel 3100. The first extension 3101 is extended by unfolding the extension through rotation in the direction of the arrows 3104 and the second extension is extended by unfolding the extension through rotation in the direction of the arrows 3105 from a position flat against the main body 3103.

As shown in FIGURE 32 a rectangular main body 3202 of the sun blocker panel 3200 may have substantially triangular extensions 3201, 3202 which may be extended and retracted from the main body by sliding translation of the extension 3201 in the direction of double-handed arrow 3204 and unfolding the extension 3202 in the direction of arrows 3205.

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The descriptions of designs for the structural support and the deployment of sun ray blocker devices written herein are examples from thousands of possible structural support and deployment designs which can be used for this purpose and are within the scope of the present invention.

This paragraph describes an example to demonstrate the geometrical approach to calculating the dimensions of a sun blocker panel for providing total shadow coverage to a quasi-rectangular shaped radiator surface. The example used is that of a radiator surface on a north or south panel of a geostationary spacecraft, like the previously defined "model" spacecraft for example, at the summer or winter solstice, when the incidence angle of the Sun's rays (measured from the plane of the benefited thermal radiator surface) is at a maximum, using a quasi-rectangular (for this simple illustration at least) shaped sun blocker panel whose plane is perpendicular to the plane of the associated thermal radiator surface (referring to FIGURE 12a, angle 501 is then 90 degree). For this example, take the north or south radiator-surface of the spacecraft to be rectangular, of length and width A and B, respectively. Then, the length and width dimensions, L and W, respectively, of the sun-exposed surface of the fully-deployed sun blocker panel (which is shown in FIGURES 16a and 17a) should be as follows: L is greater than or equal to $\sqrt{A^2+B^2}$, and W is greater than or equal to $0.435 \times \sqrt{A^2+B^2}$ based on the corresponding orbit-sun angle of 23.5 degree. However, if only a portion of the surface area on the north or south panel needs to be shadowed, i.e. high heat-dissipating

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equipments were to be mounted in certain localized areas of the north or south panel, the sun ray blocker device can be tailored to shade only those areas and may accordingly be smaller. In addition, if a sun blocker
5 panel whose plane is not perpendicular to the plane of the associated thermal radiator surface were to be selected by the spacecraft designer, the minimum value of the width, W , may be greater or less than $0.435x \sqrt{(A^2+B^2)}$ depending on the size of angle 501 in FIGURE 12a. If
10 angle 501 is greater than 90 degree, W may be greater than $0.435x \sqrt{(A^2+B^2)}$; if it is less than 90 degree, W may be less than $0.435x \sqrt{(A^2+B^2)}$. If additional shading to the other four panels, earth, zenith, east and west panels, is desired, the width (W) of the sun blocker
15 panel can be increased to extend past the imaginary plane 250 toward the center of the satellite as shown in FIGURE 7.

Thus, by the foregoing descriptions contained herein
20 it can be seen that by virtue of the present invention losses in the efficiency of the cooling of the thermal radiator panels of a spacecraft caused by solar heating can be eliminated or minimized via various sun blocking arrangements.

25

Obviously, numerous modifications to and variations on the present invention are possible in light of the above teachings. For example, as a practical matter, a designer might counterweight or counterbalance the
30 rotating axles or arms to overcome the weight imbalance caused by sun ray blocker devices of the present invention without exceeding the scope of the present

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invention. It is therefore understood that within the scope of the appended claims, the invention may be practiced otherwise than as specifically described herein.

5

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CLAIMS

1. A spacecraft for orbiting a sunlit celestial body (300), the spacecraft including a thermal radiator surface (11,12,1804, 2121, 2721) for radiating heat
5 from the spacecraft into space, and a sun ray blocker device (111,112, 141, 271, 301, 411, 511, 611, 811, 921, 951,1800,2100, 2700) mounted on said spacecraft for shielding said thermal radiator surface (11,12,1804,2121,2721) from rays of sunlight,
10 characterised in that said sun ray blocker device is locatable for placing in shadow substantially the whole of the thermal radiator surface (11,12,1804,2121,2721) from sunlight without substantially impeding thermal radiation from said thermal radiator surface
15 (11,12,1804,2121,2721) into space.
2. A spacecraft as claimed in claim 1, wherein an effective radiation view factor for thermal radiation from the thermal radiator surface (11,12,1804, 2121,2721) to deep space is significantly greater than
20 corresponding geometrical radiation view factor to deep space, and in particular, for a geostationary spacecraft where the geometrical radiation view factor to deep space is 0.65, the effective radiation view factor to deep space is at least 0.87.
- 25 3. A spacecraft as claimed in claims 1 or 2, wherein the sun ray blocker device includes at least one sun blocker panel (111, 112) having a sun-facing surface (111a, 112a) and an opposed anti-sun-facing surface (111b, 112b), wherein the sun-facing surface (111a,

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112a) is thermally insulated from the opposed surface (111b, 112b).

4. A spacecraft as claimed in claim 3, wherein the sun-facing surface (111a, 112a) is thermally insulated from the opposed surface (111b, 112b) by a multi-layer insulation blanket.
5. A spacecraft as claimed in claims 3 or 4, wherein the sun-facing surface (111a, 112a) has a low solar energy absorptivity of less than 0.5.
- 10 6. A spacecraft as claimed in any of claims 3 to 5, wherein the sun-facing surface (111a, 112a) includes a solar cell panel for supplying electrical power to the spacecraft.
- 15 7. A spacecraft as claimed in any of claims 3 to 6, wherein the sun-facing surface (111a, 112a) has a high thermal emissivity of higher than 0.7.
- 20 8. A spacecraft as claimed in any of claims 3 to 7, wherein the sun ray blocker device (111, 112, 141, 271, 301, 411, 511, 611, 811, 921, 951, 1800, 2100, 2700) is moveable between a stowed, non-operative position and a deployed operative position.
- 25 9. A spacecraft as claimed in any claims 3 to 8, wherein the sun ray blocker device (111, 112, 141, 271, 301, 411, 511, 611, 811, 921, 951, 1800, 2100, 2700) includes an attachment arm (207, 205, 430, 230) for attaching the sun blocker panel (111, 112) to the spacecraft.

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10. A spacecraft as claimed in claim 9, wherein the attachment arm (207, 205, 430, 230) is attached by a hinge means(406, 306) to the sun blocker panel (111, 112) and/or by a second hinge means(407, 507, 607, 307) to the spacecraft.
11. A spacecraft as claimed in any of claims 8 to 10, wherein the sun ray blocker device (111,112; 141; 271; 301; 411; 511; 611; 811; 921; 951) includes a motor for moving the sun ray blocker device (111,112; 141; 271; 301; 411; 511; 611; 811; 921; 951) between the stowed position and the deployed position.
12. A spacecraft as claimed in any of claims 3 to 11, wherein locating means are provided for locating the sun ray blocker device (111,112; 141; 271; 301; 411; 511; 611; 811; 921; 951) with respect to the thermal radiator surface (11,12) which includes adjustment means to maintain the majority of the thermal radiator surface (11,12) in shadow irrespective of changes in the attitude and/or orbit of the spacecraft during normal operations.
13. A spacecraft as claimed in claim 12, wherein the adjustment means includes a variable length attachment arm (2130, 2730)for attachment of the sun blocker panel to the spacecraft.
14. A spacecraft as claimed in claim 13, wherein the attachment arm is a scissor arm (2730).
15. A spacecraft as claimed in claim 13, wherein the attachment arm (2130)is formed of articulated portions (2132, 2134, 2137) which may be mutually articulated

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15. A spacecraft as claimed in claim 13, wherein the transport means includes rail means (2002) and belt means (2003) connected to the carriage means (2001), the belt means being driven by drive means (2030) to
5 move the carriage means along the rail means (2002).
16. A spacecraft as claimed in claim 13, wherein the carriage means includes an annulus (1920) rotatable in a circular path defined by bearing means (1903) the annulus being driveable by drive means (1930) to move
10 the carriage along the path defined by the bearing means.
17. A spacecraft as claimed in any of claims 12 to 16, having a solar cell array (100, 101, 408) adapted for tracking movements of the Sun relative to the
15 spacecraft, wherein the adjustment of the location of the sun ray blocker device (111, 112, 141, 271, 301, 411, 511, 611, 811, 921, 951) in relation to the thermal radiator surface (11, 12, 1804, 2121, 2721) is synchronised with the tracking movement of the solar
20 cell array, when in normal operation.
18. A spacecraft as claimed in claim 17, wherein the sun ray blocker device (111, 112; 141; 271; 301; 411; 511; 611; 811; 921; 951) is mounted on the solar cell array (100, 101 408) or on means carrying said solar cell
25 array.
19. A spacecraft as claimed in claim 18, wherein the solar cell array tracks the movement of the Sun by rotation of the solar cell array about an axis of rotation of the solar cell array (100, 101, 408) such

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that the sun blocker panel (111, 112) also rotates about said axis of rotation of the solar cell array.

20. A spacecraft as claimed in claim 19, wherein the thermal radiator surface (11,12) is orthogonal to the axis of rotation of the solar cell array so that the sun blocker panel (111, 112) rotates about an axis normal to the thermal radiator surface.
21. A spacecraft as claimed in claim 18-20, wherein the adjustment means includes a variable length attachment arm (2130, 2730) for attachment of the sun blocker panel to the spacecraft.
22. A spacecraft as claimed in claim 21, wherein the attachment arm is a scissor arm (2730).
23. A spacecraft as claimed in claim 21, wherein the attachment arm (2130) is formed of articulated portions (2132, 2134, 2137) which may be mutually articulated during rotation to vary an effective length of the attachment arm.
24. A spacecraft as claimed in any of claims 21-23, wherein the adjustment means for attachment of the sun blocker panel (2100, 2700) to a solar cell array assembly (2131, 2701) are such that a distance between the sun blocker panel from the solar cell array assembly (2130, 2730) may be varied during rotation of the sun blocker panel.
25. A spacecraft as claimed in any of claims 3 to 24, wherein means (929, 931, 955, 957) are provided for adjusting the size of the sun blocker panel (111, 112).

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26. A spacecraft as claimed in any of the preceding claims, including control means for controlling the spacecraft so as to maintain an angle between a sun line and the thermal radiator surface (11,12) below a
5 predetermined angle by adjustment of the orbit and/or attitude of the spacecraft in use.
27. A spacecraft as claimed in claim 26, wherein the predetermined angle is 60 degrees.
28. A spacecraft as claimed in claims 26 or 27, wherein
10 the control means is adapted to maintain the thermal radiator surface (11,12) substantially parallel to a plane of an orbit of the spacecraft.
29. A spacecraft as claimed in any of claims 26 to 28,
15 wherein the control means is adapted to maintain the spacecraft in a sun synchronous orbit.
30. A spacecraft as claimed in any of claims 26 to 28, wherein the control means is adapted to maintain the spacecraft in an equatorial or low-inclination orbit.
31. In a three axis stabilised spacecraft for orbiting
20 about a planet and having at least one solar cell assembly having at least one solar cell panel, and being a north solar cell panel assembly or a south solar cell panel assembly, said at least one solar cell panel assembly being mounted on an axle so as to be
25 controllably rotated from said spacecraft about an axis of rotation so as to face the Sun, said spacecraft having a nadir panel which is generally pointing to the centre of the planet, an opposite panel known as a zenith panel, which faces away from the centre of the

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planet and sharing the same planar normal vector as said nadir panel, an east panel and a west panel, said east panel and said west panel having their planar normal vector laying on a orbital plane pointing to the velocity vector of the spacecraft generally tangential to the direction of travel on the orbit, and a north panel and a south panel, said north panel and said south panel having their planar normal vector generally perpendicular to the orbit plane and parallel to the axis of rotation of the planet, said solar cell panel extending outwardly from said spacecraft, the improvement which comprises:

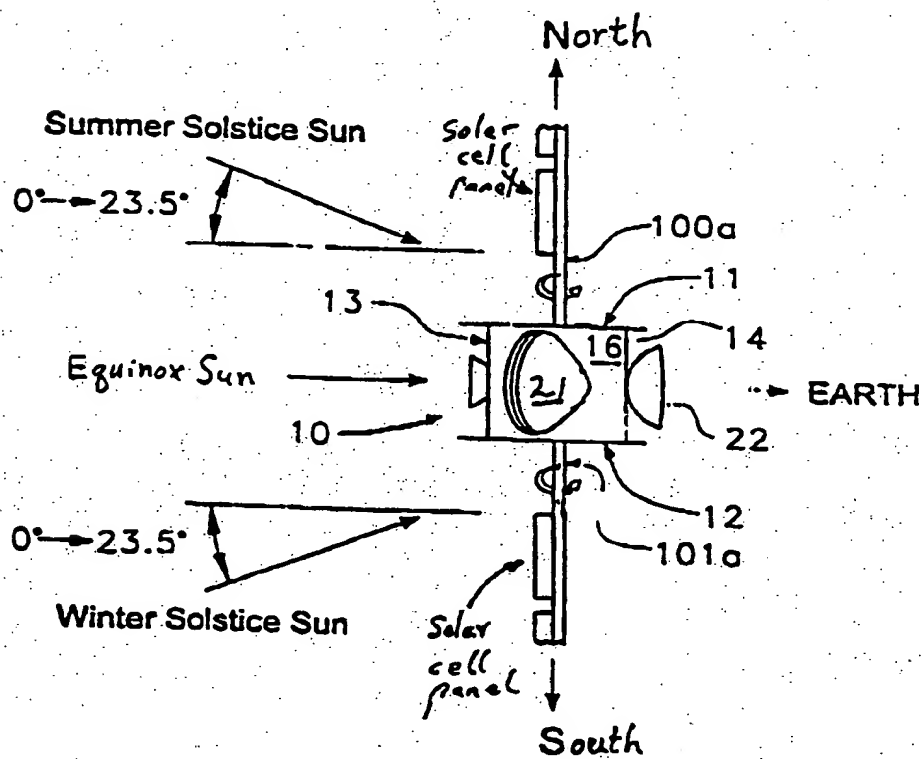
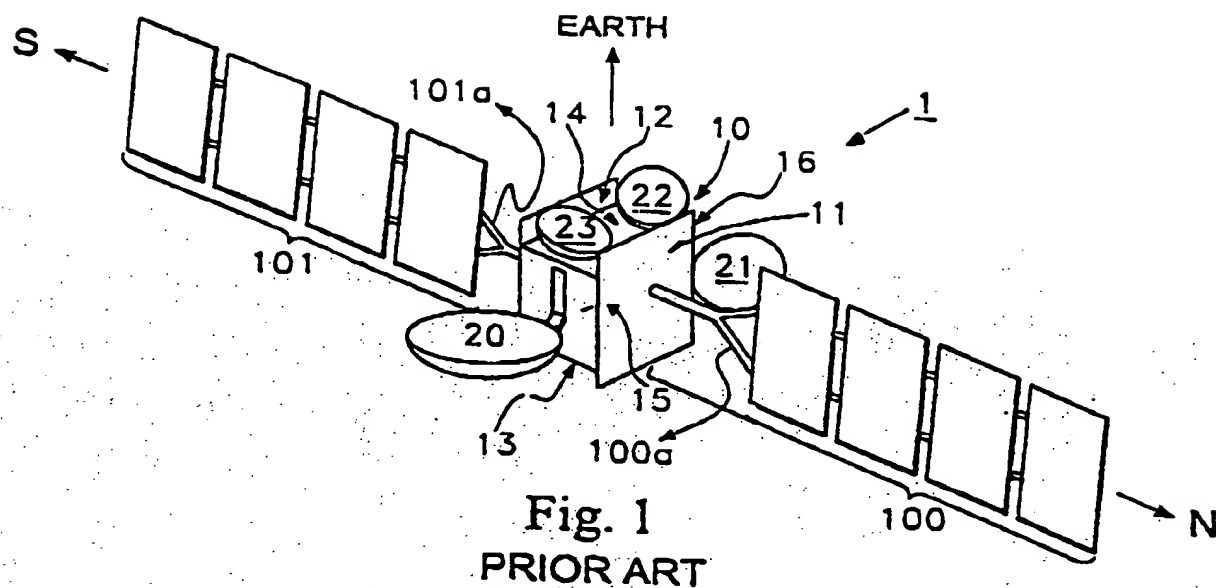
attaching at least one sun ray blocker device to said at least one solar cell panel, said at least one device being either a north blocker device or being a south blocker device and corresponding to said at least one solar cell panel, each of said at least one sun ray blocker device being positioned forwardly from and offset relative to a solar cell surface of a solar cell panel and at a predetermined angle to either of said north panel and said south panel, said north panel or said south panel, said sun ray blocker device being positioned so as to cast a shadow on at least a majority of the exposed surface of its corresponding north or south panel during solar exposure thereto.

32. In a three axis stabilised low inclination orbit spacecraft for orbiting about the earth and having two sets of solar cell array assemblies having solar cell arrays, one set being a north solar array assembly and the other being a south solar array assembly, said assemblies each being mounted on an axle so as to be

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controllably rotated from said spacecraft about an axis of rotation so as to face the Sun, said spacecraft having an earth panel which is generally pointing to the centre of the earth, an opposite panel known as a zenith panel, which faces away from the centre of the earth and sharing the same planar normal vector as said earth panel, an east panel and a west panel, said east panel and said west panel having their planar normal vector laying on an orbital plane pointing to the velocity vector of the spacecraft generally tangential to the direction of travel on the orbit, and a north panel and a south panel, said north panel and said south panel having their planar normal vector generally perpendicular to the orbit plane and parallel to the axis of rotation of the earth, said solar cell panel extending outwardly from said spacecraft, the improvement which comprises:

attaching at least one sun ray blocker device to each of said north solar array and said south solar array, one device being a north device and another device being a south device, each of said sun ray blocker devices being in the form of a panel and being positioned forwardly and offset relative to the solar cell surface of a solar ray and at a predetermined angle to said north panel and said south panel, said north blocker device being positioned so as to cast a shadow on at least a majority of the exposed surface of said north panel during solar exposure thereto, and said south blocker device being positioned so as to cast a shadow on the exposed surface of said south panel during solar exposure thereto.



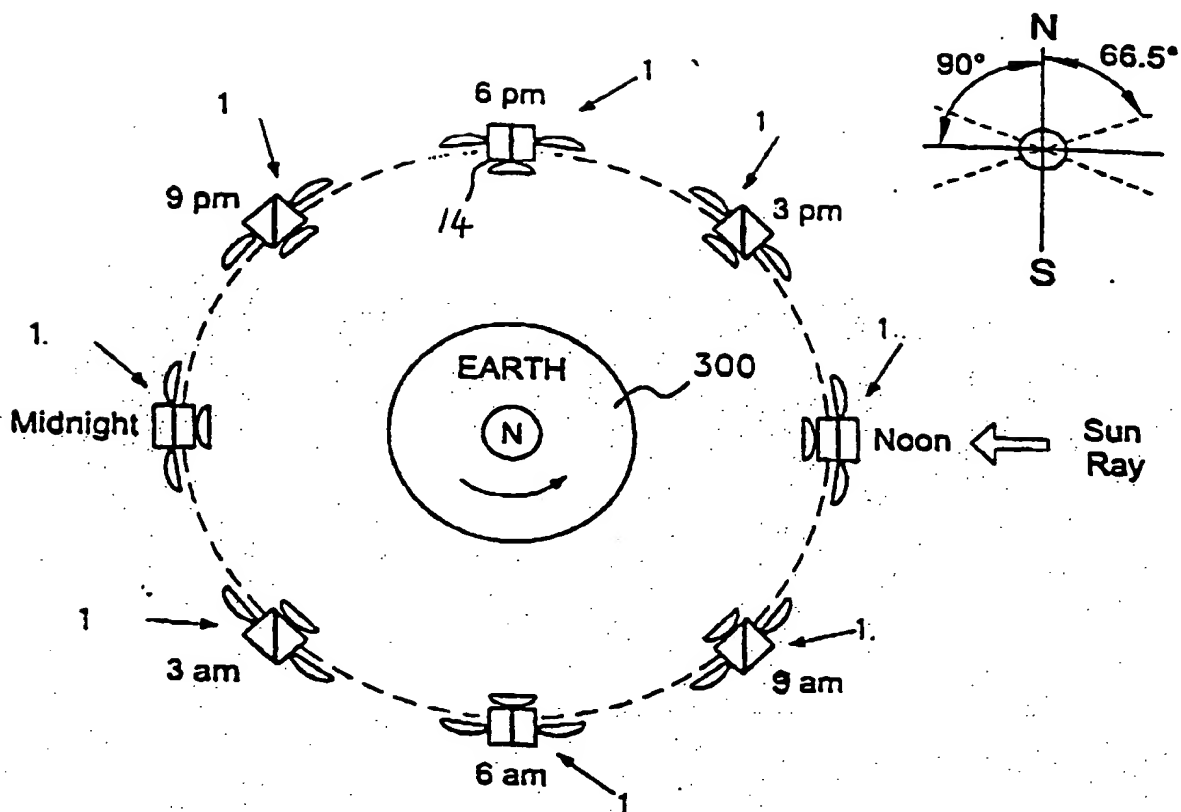


Fig. 3a
PRIOR ART

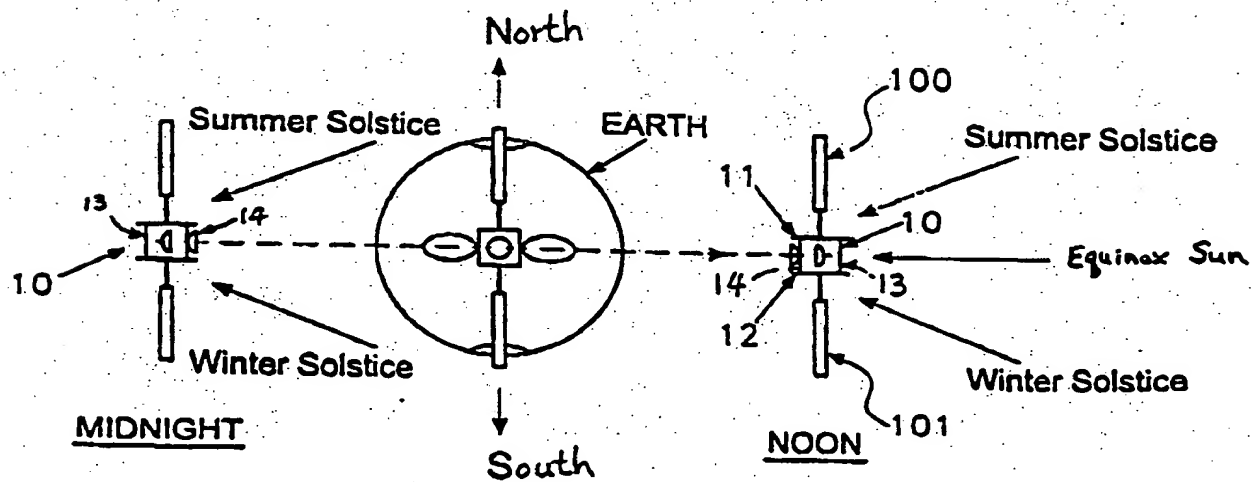


Fig. 3b
PRIOR ART

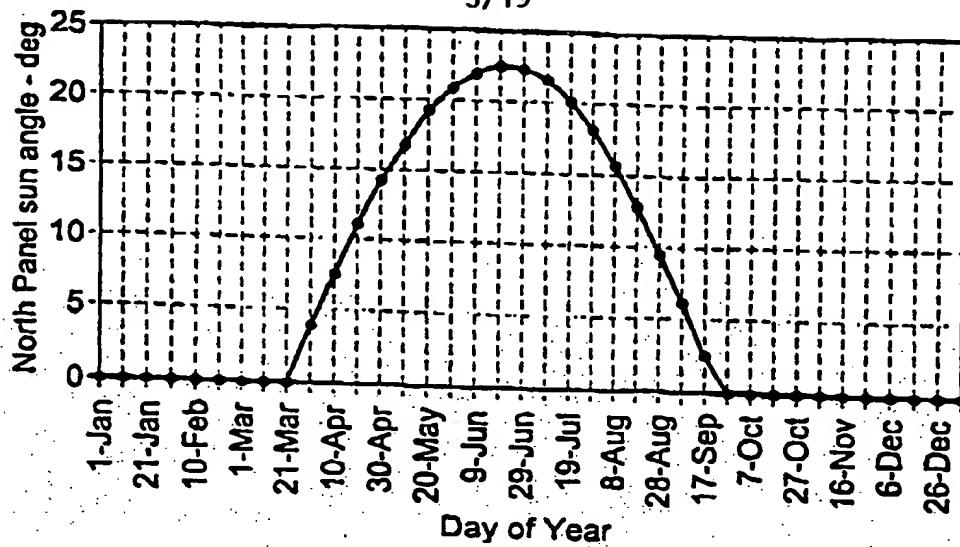


Fig. 4a

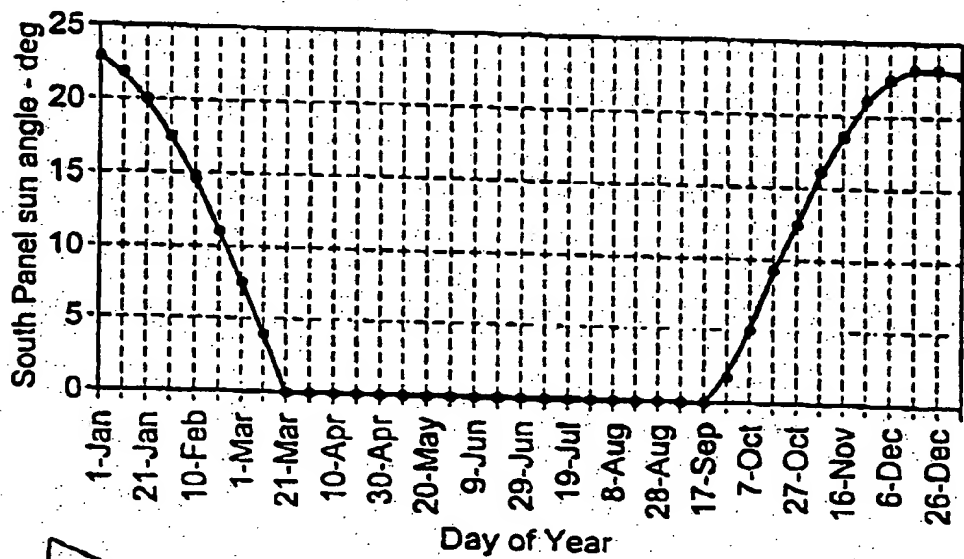


Fig. 4b

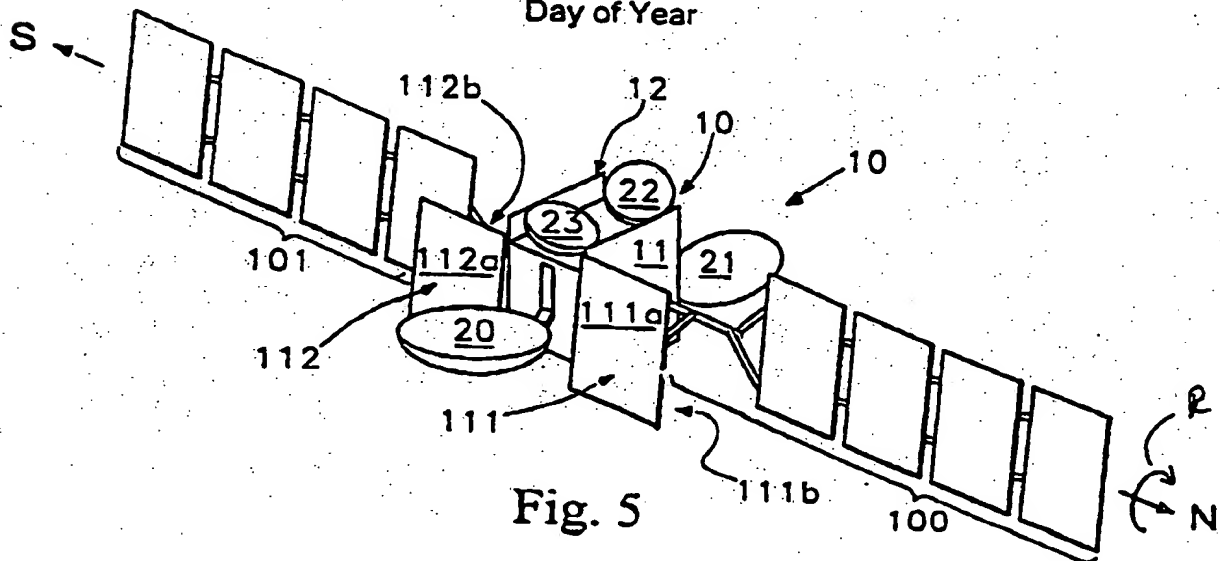


Fig. 5

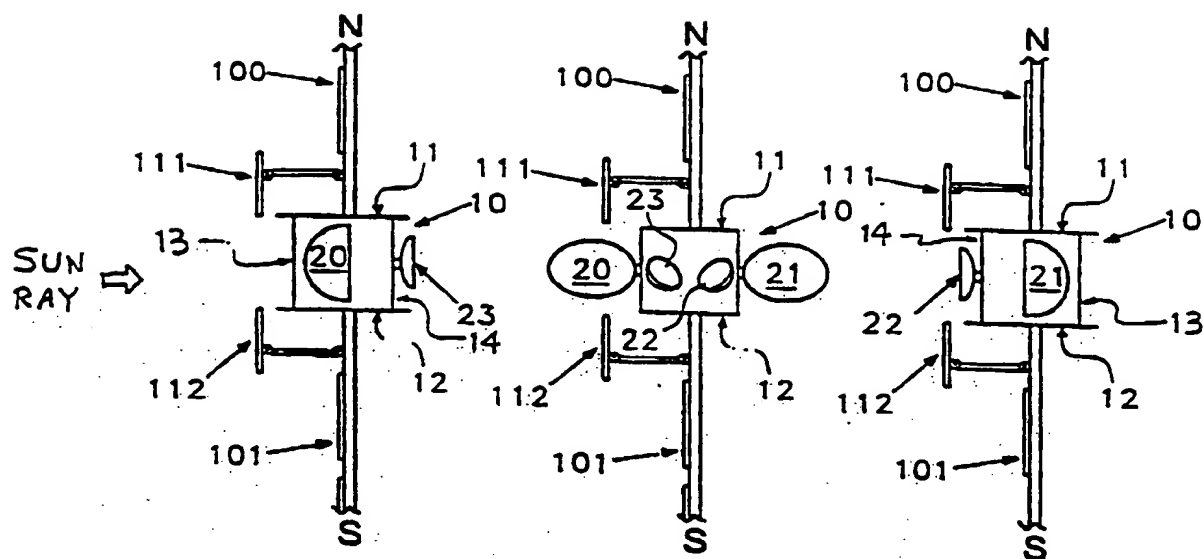


Fig. 6a

Fig. 6b

Fig. 6c

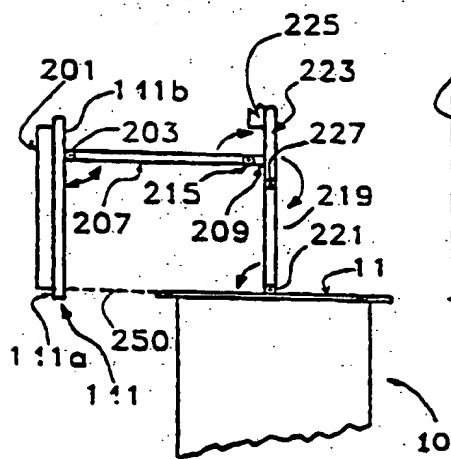


Fig. 7

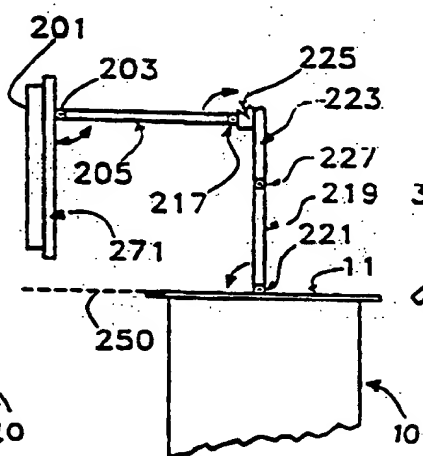


Fig. 8

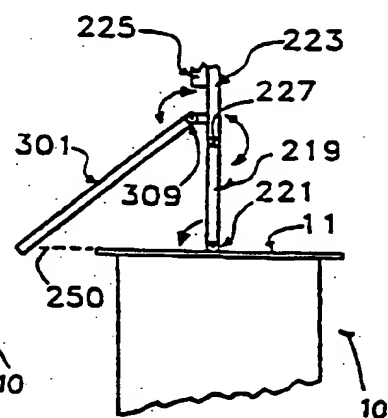
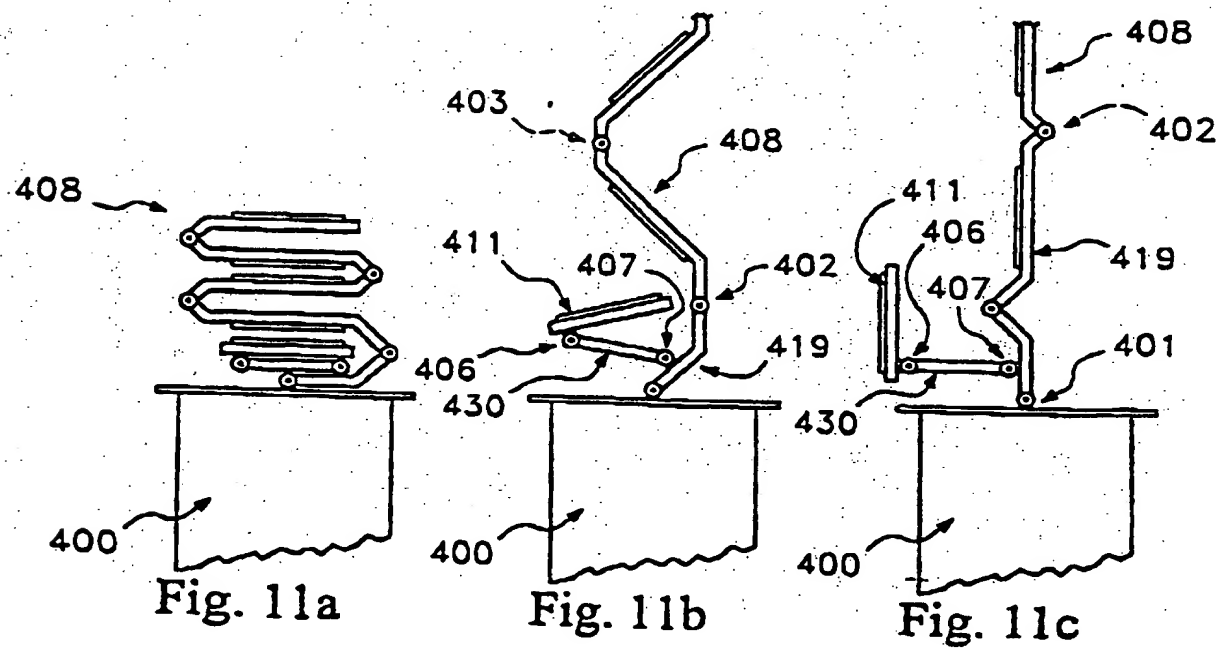
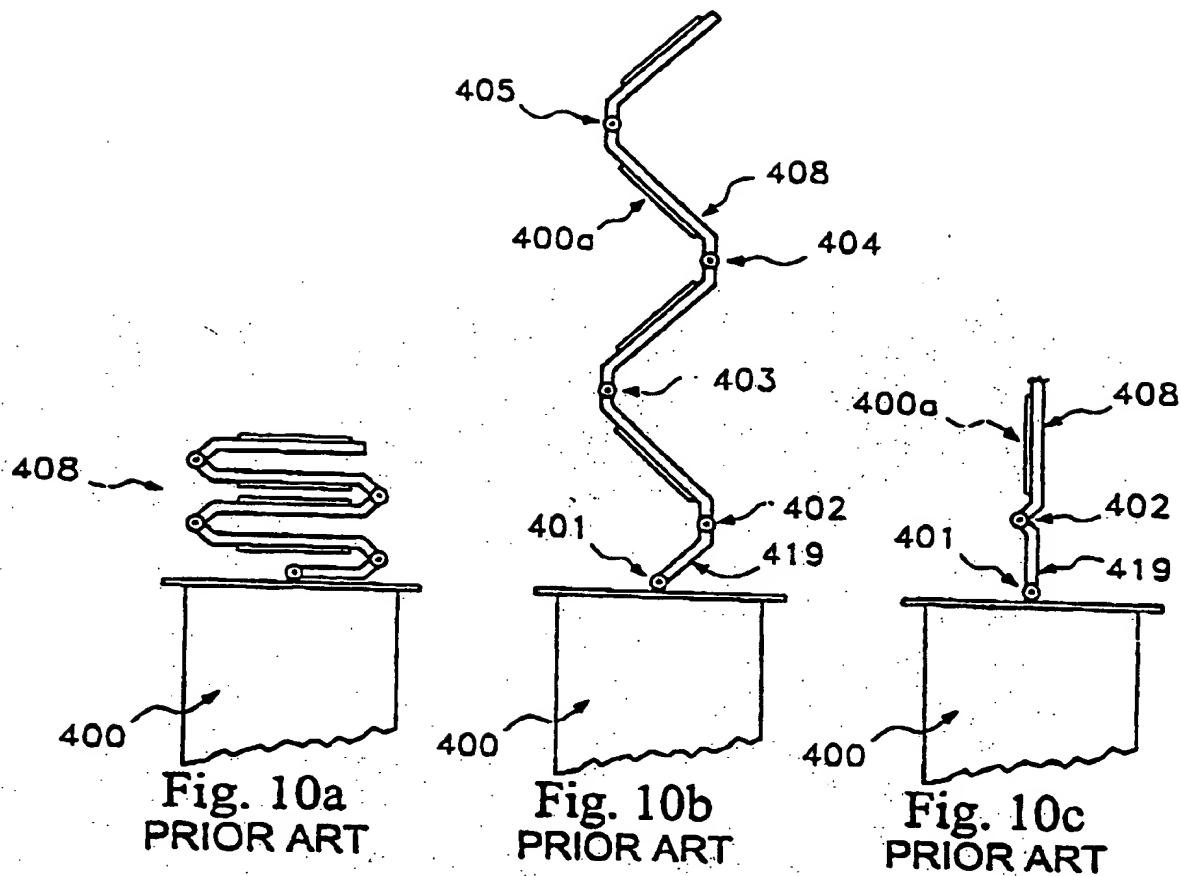


Fig. 9



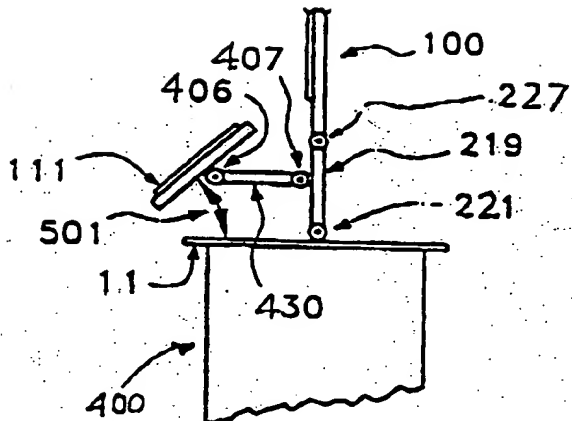


Fig. 12a

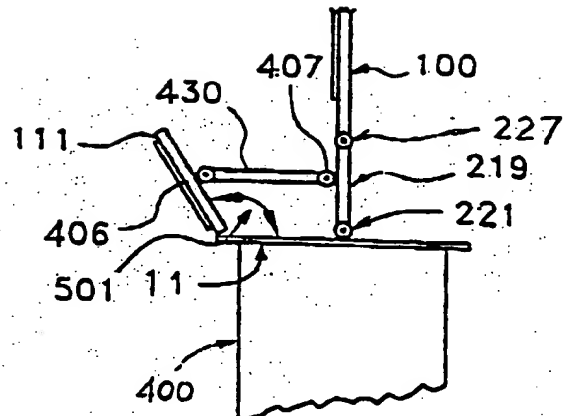


Fig. 12b

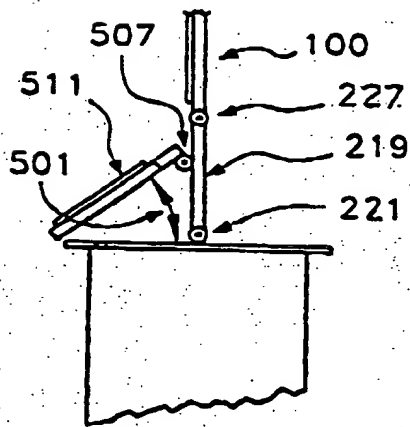


Fig. 13

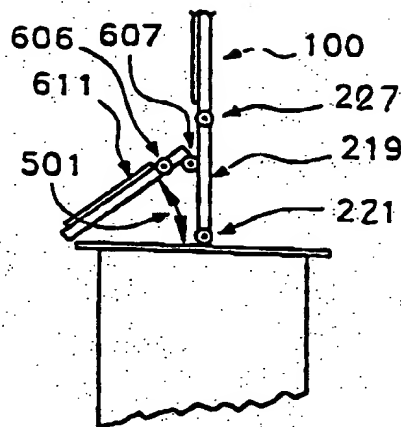


Fig. 14a

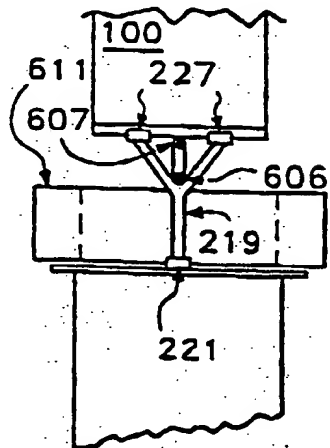
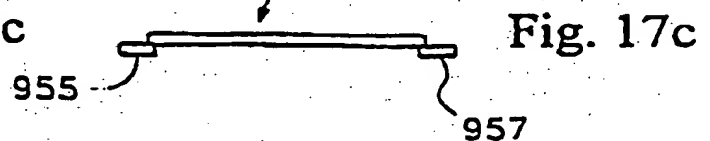
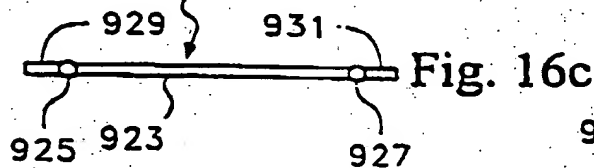
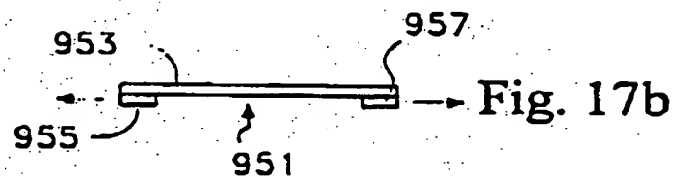
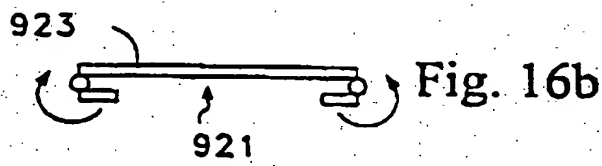
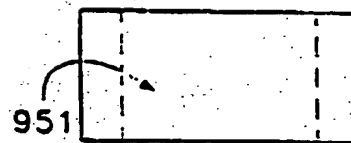
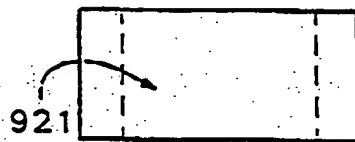
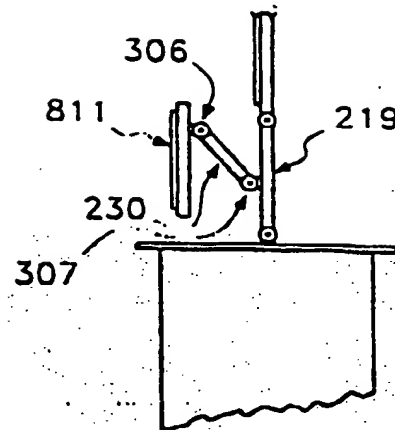
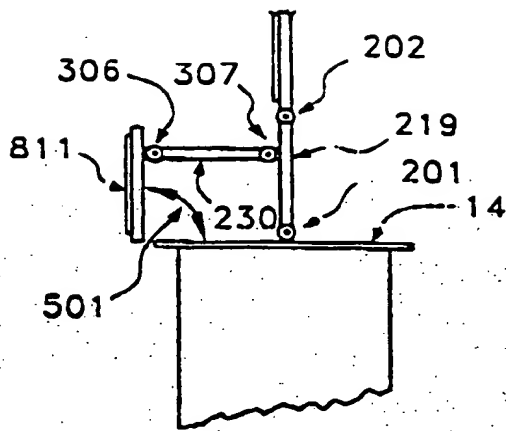


Fig. 14b



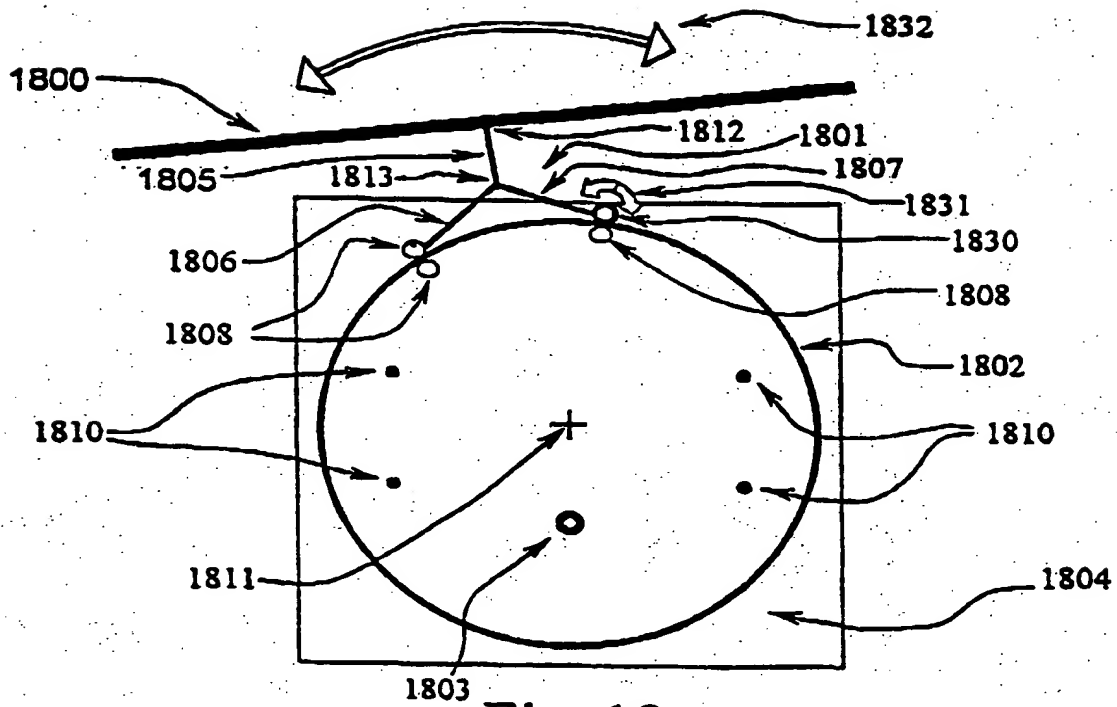


Fig. 18

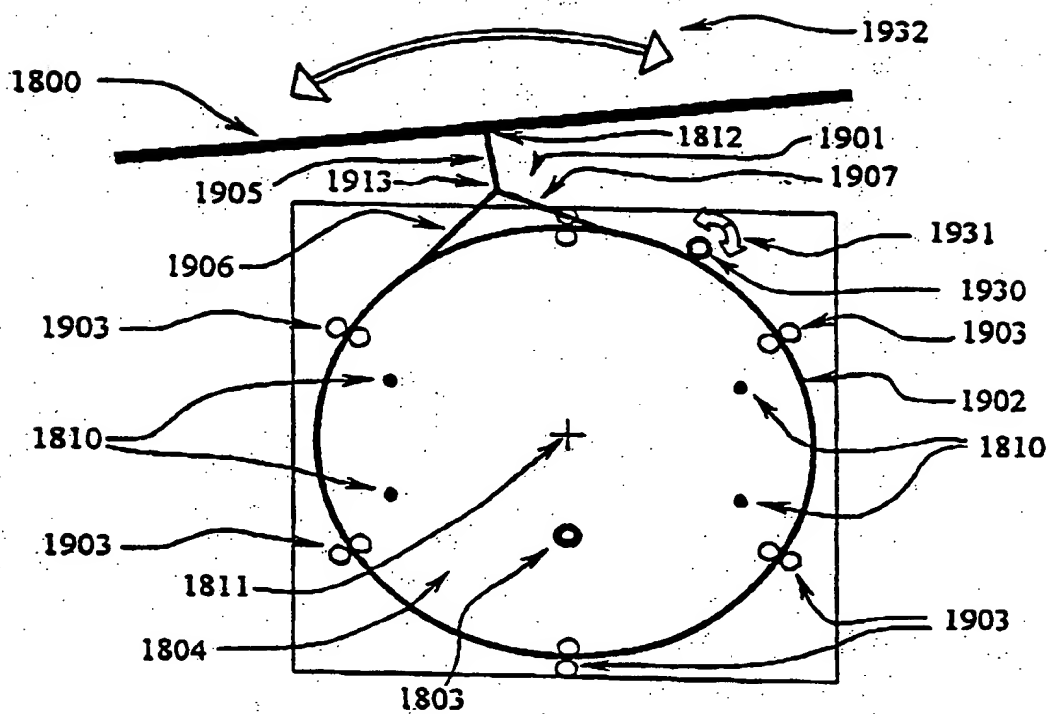


Fig. 19

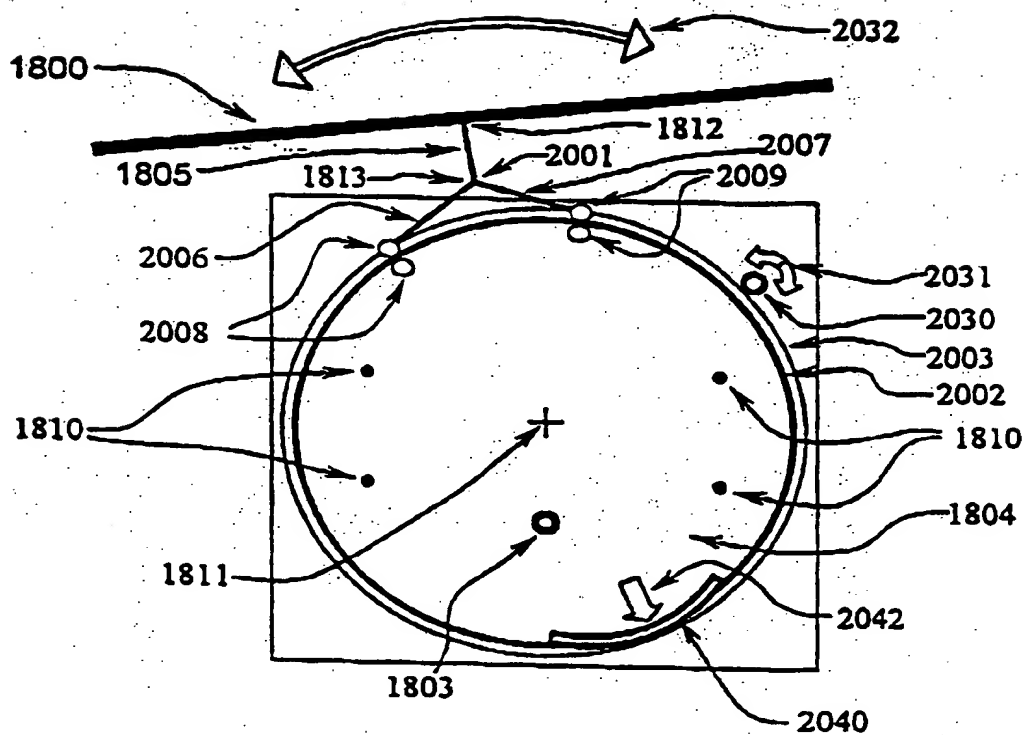


Fig. 20

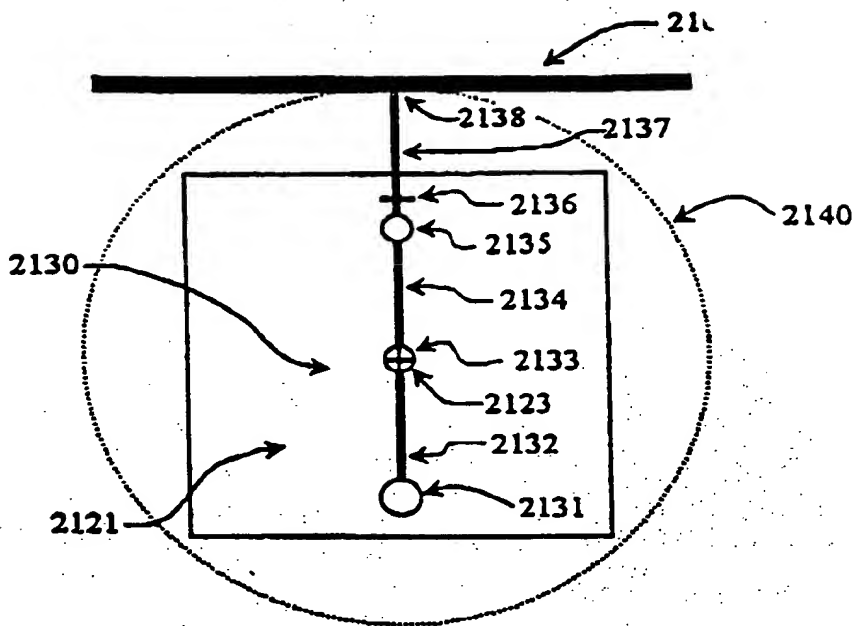


Fig. 21

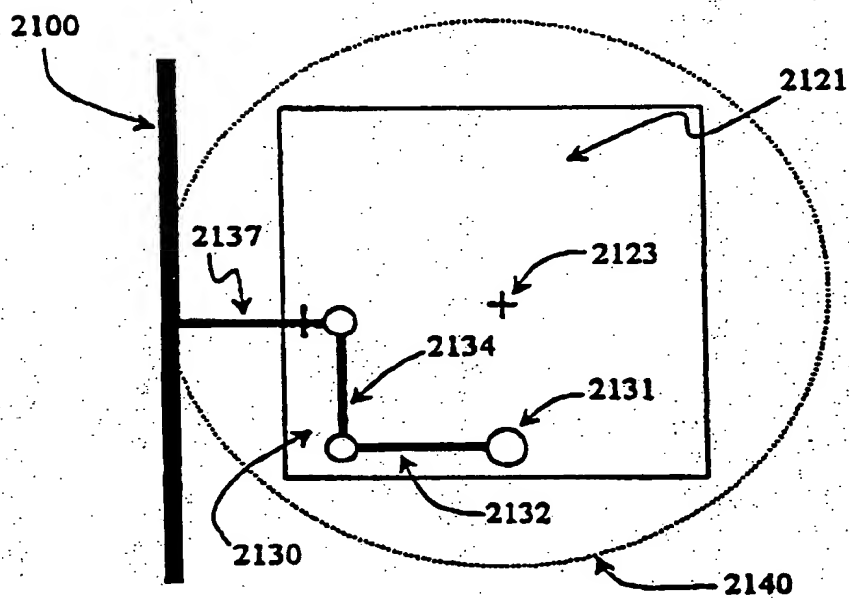


Fig. 22

Diagram of a circuit 2100. The circuit includes a feedback loop 2130 that includes a first node 2131, a second node 2132, and a third node 2137. A first branch 2121 includes a first node 2131 and a first node 2123. A second branch 2140 includes a second node 2132 and a second node 2137. A third branch 2134 includes a third node 2137 and a third node 2131. A fourth branch 2132 includes a fourth node 2132 and a fourth node 2137. A fifth branch 2130 includes a fifth node 2130 and a fifth node 2137.

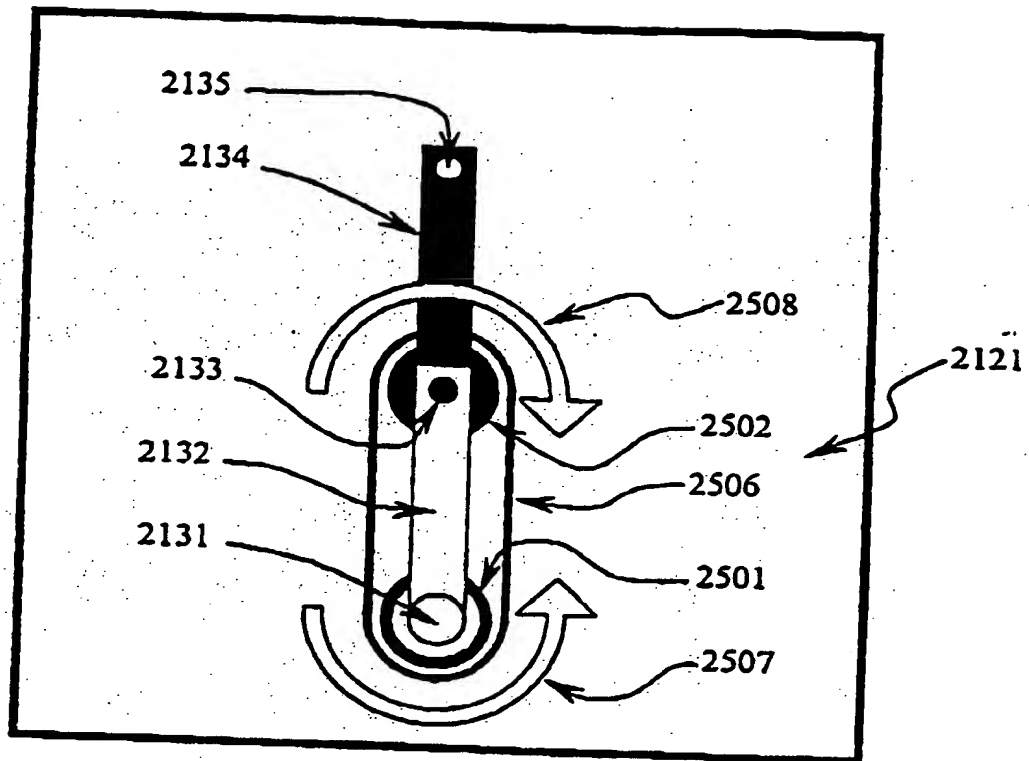


Fig. 25

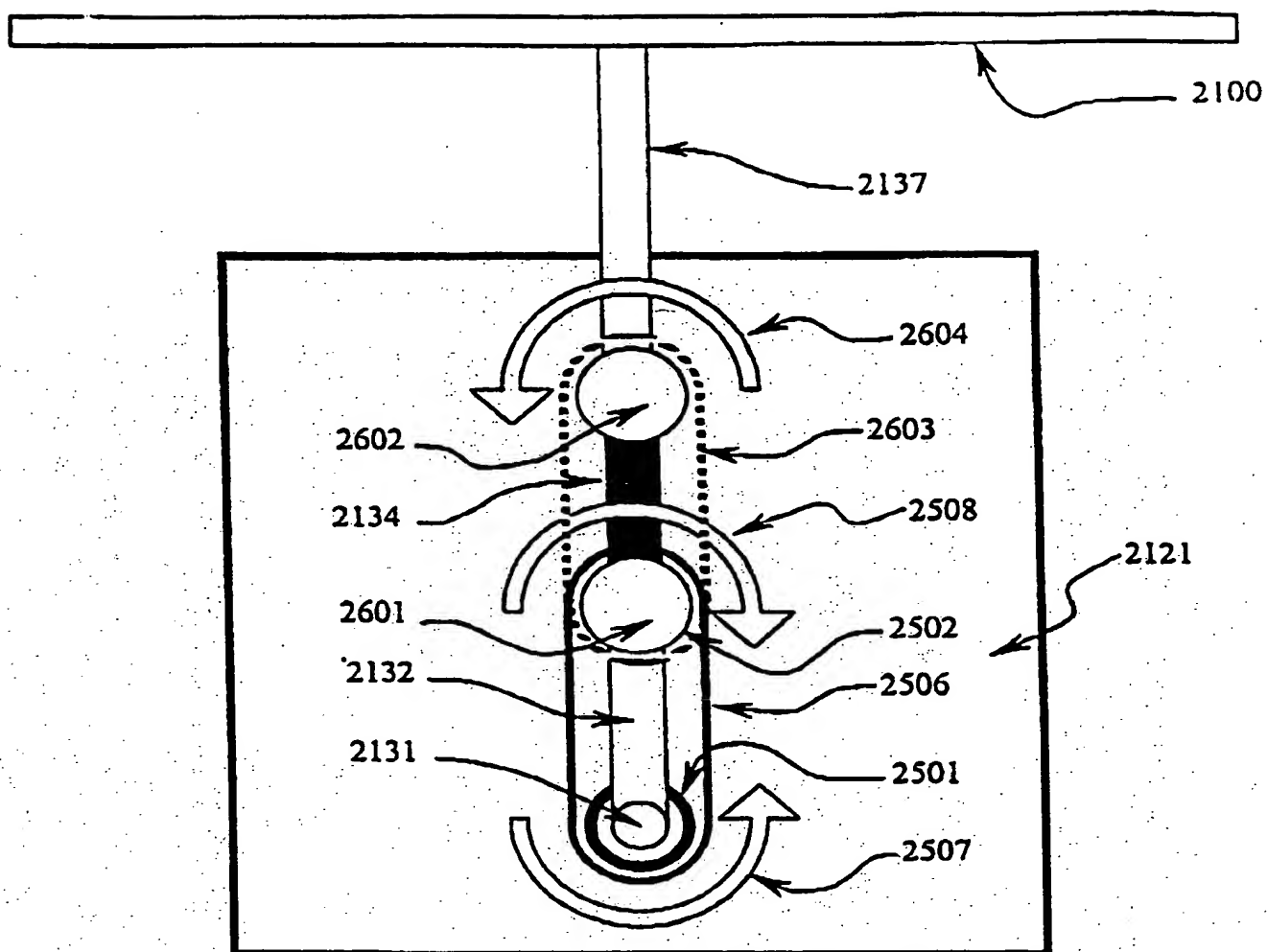


Fig. 26

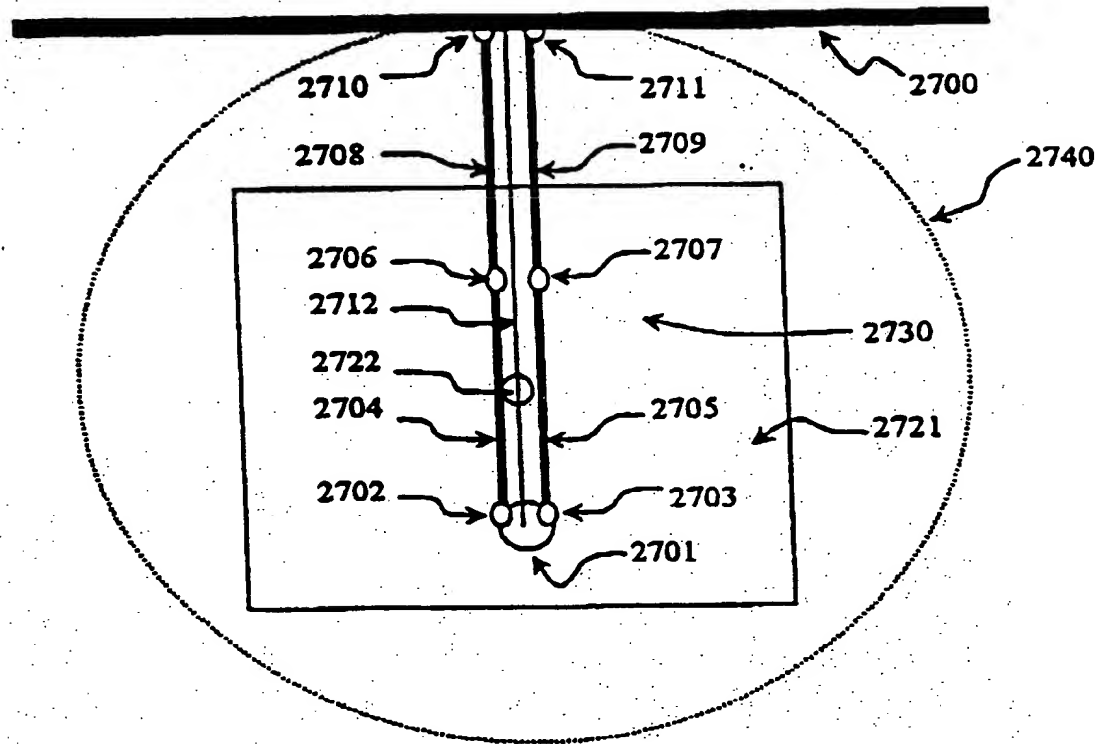


Fig. 27

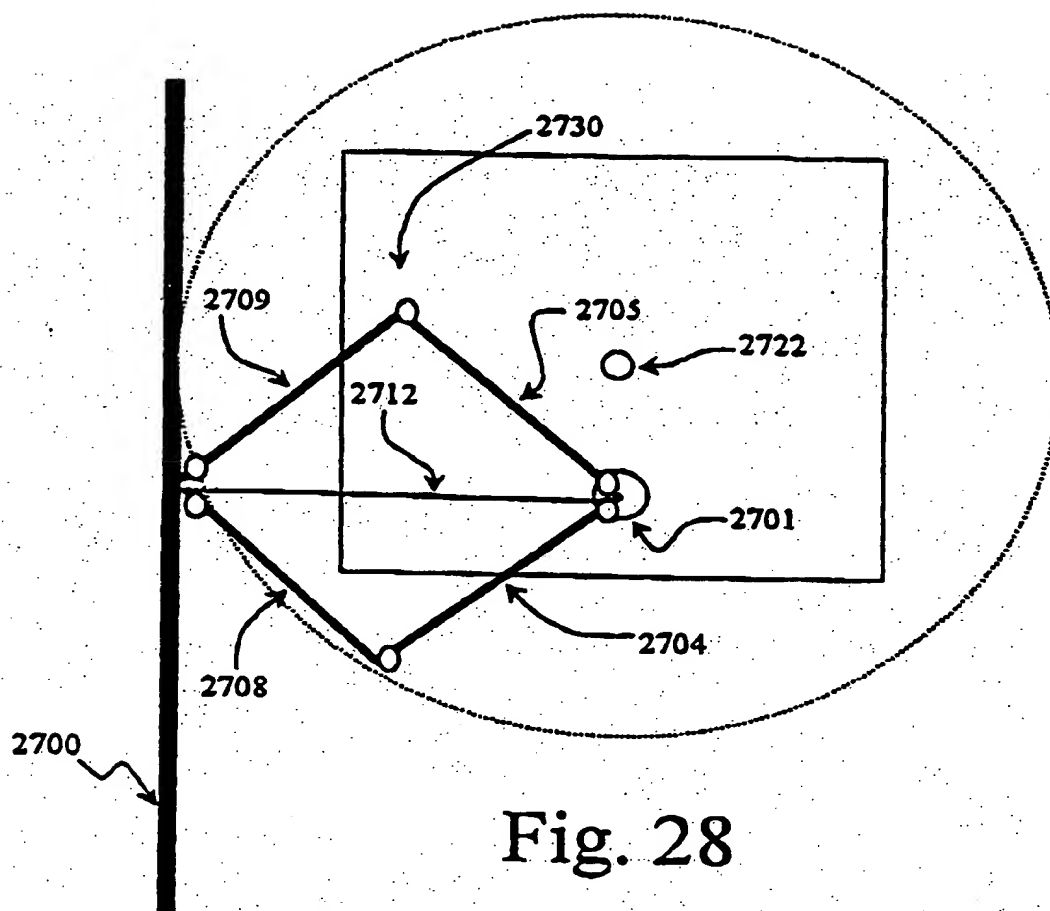


Fig. 28

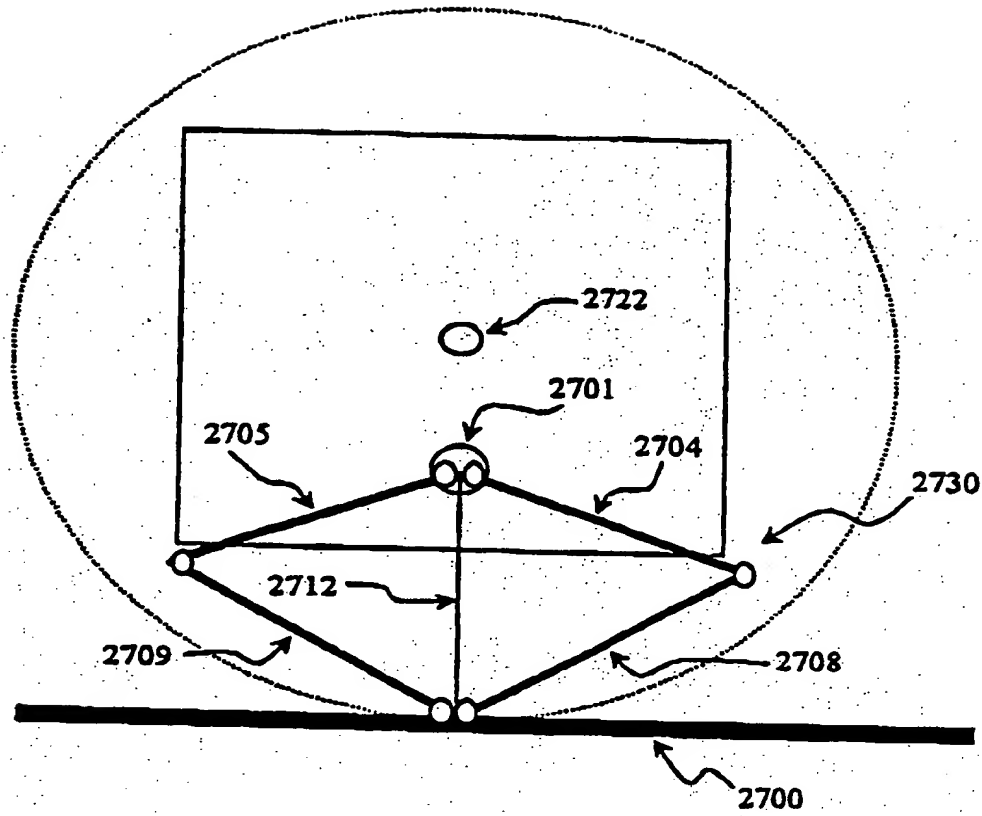
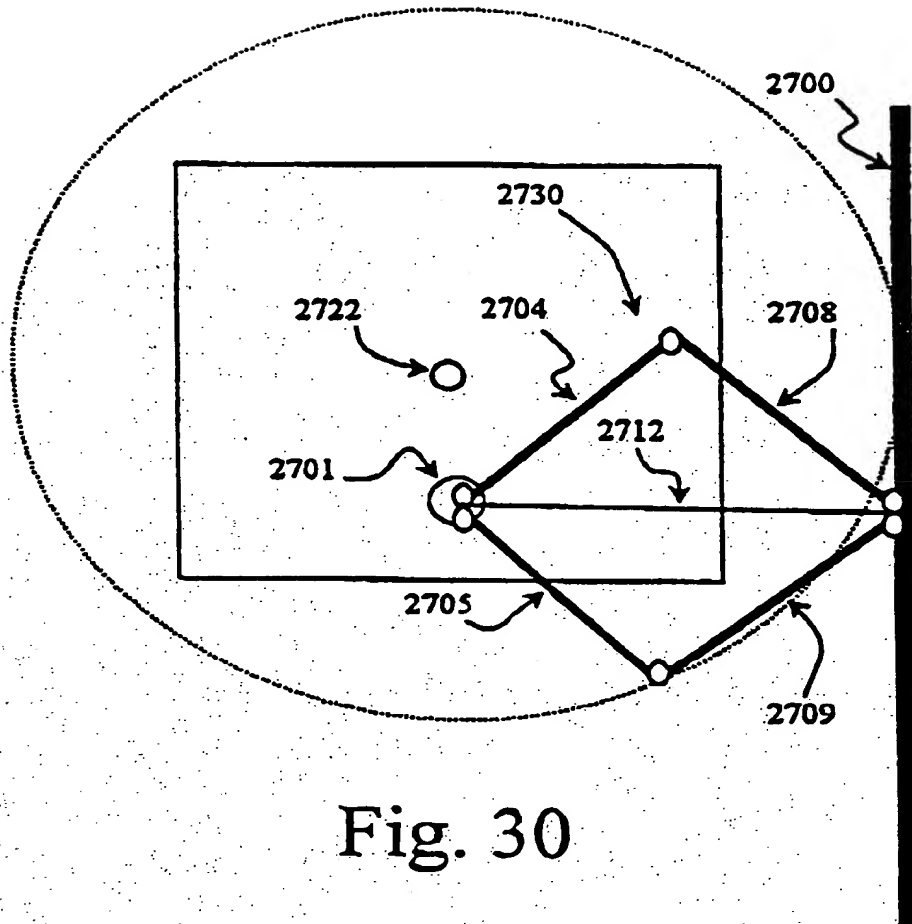


Fig. 29



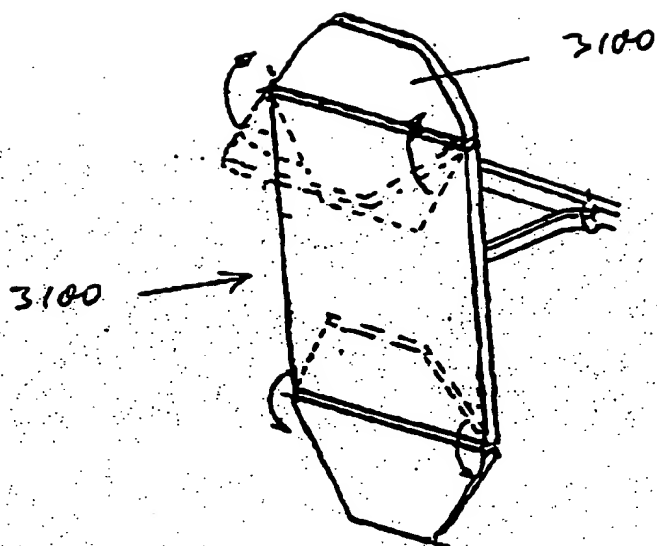


Fig. 31

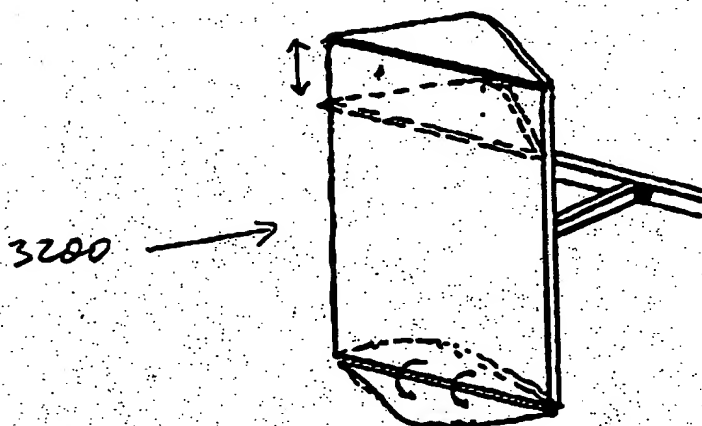
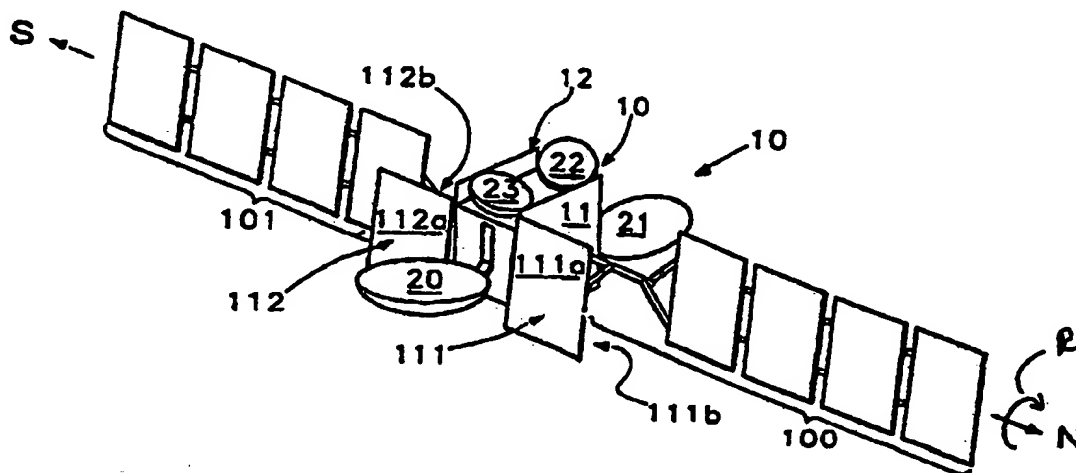


Fig. 32



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(71)(72) Applicant and Inventor: KASKIEWICZ, Paul [US/US]; 216 East Street, Philadelphia, PA 19128 (US).			
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(75) Inventors/Applicants (for US only): LIU, Linchih, Oliver [US/US]; 12 Indian Run Road, Princeton, NJ 08550 (US). WU, Albert, T. [US/US]; 167 West Mudland Avenue, Paramus, NJ 07652 (US).			

(54) Title: SPACECRAFT SHADING DEVICE

(57) Abstract

A spacecraft having a sun ray blocker device (111, 112, 141, 271, 301, 411, 511, 611, 811, 921, 951, 1800, 2100, 2700) for shading a thermal radiator surface (11, 12) of the spacecraft in which the sun ray blocker device is movable in relation to the thermal radiator surface to keep the surface substantially in shade without substantially blocking thermal radiation from the thermal radiator surface to deep space. Preferably a sun-facing side (111a, 112a) of the sun ray blocker device is thermally insulated from an opposed side (111b, 112b) to reduce thermal radiation from the sun ray blocker device to the thermal radiator surface and the sun ray blocker device is also preferably deployable in orbit after launch.

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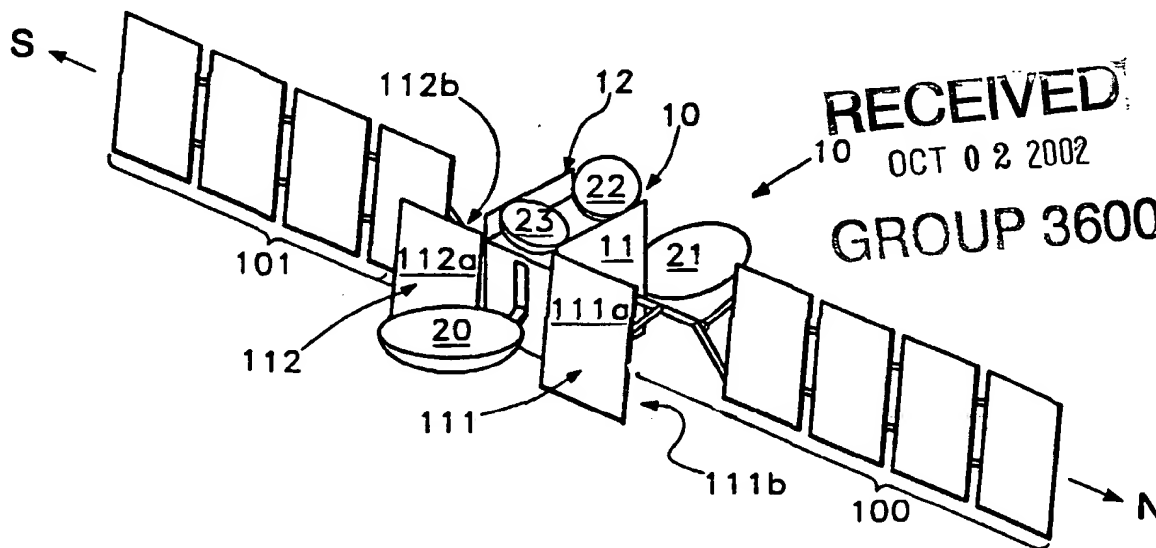
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- (72) Inventor; and
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SPACECRAFT SHADING DEVICE

The present invention relates to a spacecraft and particularly to a spacecraft having a sun ray blocker device for shading thermal radiator surfaces on said spacecraft from solar heating.

The following patents are generally representative of the prior art in the broad fields of solar array related sun shields, solar array deployment mechanisms, and the thermal control of radiator surfaces for various types of spacecraft.

United States Patent 4,133,502 to Andrew Anchutin describes a plurality of arrays of solar cells which are symmetrically stored about a spacecraft during launch to provide symmetrical loading. When the spacecraft is in operational configuration, the solar arrays are deployed adjacent each other on one side of the spacecraft to effectively form a single array and the single array may be oriented to face the Sun by a common drive mechanism.

United States Patent 4,508,297 to Guy G. Mouilhayrat et al, describes an equatorial orbit satellite with solar panels having blades with a median line inclined at a certain angle relative to the equatorial plane. Thus, the field of vision of the antennas is free and disturbing torques become acceptable.

United States Patent Number 5,372,183 to Harold P. Strickberger describes a spacecraft adapted for operation

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in a low inclination angle earth orbit which comprises north, south, east and west panels defining a spacecraft interior volume. The north and south panels are oppositely disposed with respect to each other and the east and west panels are oppositely disposed with respect to each other. The spacecraft interior volume generally and preferably lacks structural elements that substantially restrict thermal radiation among the panels. The north and south panels, to which spacecraft equipment is usually mounted, each include conductive heat pipes for reducing the temperature difference across each panel. The exterior surfaces of the north, south, east and west panels have a covering, preferably of optical solar reflectors (OSRs), for radiating thermal energy therefrom, wherein the OSRs have a solar absorptivity that is substantially less than their thermal emissivity. The interior surfaces of the north, south, east and west panels have a covering for effectively radiating thermal energy between and among the panels across the interior volume.

United States Patent 4,725,023 to Haruo Shiki describes a geostatic satellite which comprises a spinning drum for stabilization which spins around an axis of rotation which is parallel to the axis of the Earth. A paddle member loaded with solar cells is directly rotatable about the same axis and is controlled such that the solar cells face the Sun. A de-spun platform supports communication gear and maintains the gear pointed to a relatively fixed point on Earth. A shading device for shading the electronics laden de-spun platform from the Sun is attached to the paddle member

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and rotatable therewith. Thereby, the shading device will always be disposed between the Sun and the de-spun platform. However, the shading device also blocks thermal radiation from the platform and also itself heats
5 up in sunlight and radiates heat towards the platform, decreasing the efficiencies of heat transfer from the spacecraft to space.

Notwithstanding the prior art, the present invention
10 is neither taught nor rendered obvious thereby.

It is an object of this invention substantially to reduce or eliminate the direct and indirect solar heating of certain spacecraft radiator-panels, and to also
15 minimize the magnitude of any reduction in the radiative-view-factor of the (shielded) radiator panel. In order to achieve that objective, the materials and design selected for the sun ray blocker device, which will be discussed below, should ideally provide all of the
20 following: minimum blockage of the field-of-view to deep space of its associated radiator surface(s), low absorption of the solar energy incident on its front (sunward) surface, high radiation of absorbed thermal energy back to space, and high insulation of heat between
25 the front (sunward) and back (anti-sunward) sides of the sun ray blocker device.

It is also desirable to provide a sun ray blocker device that is capable of greatly reducing or eliminating
30 solar energy incident on those sides of certain spacecraft relative to which the Sun direction makes a low angle. The types of spacecraft to which the present

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invention applies include some spacecraft for operation in equatorial or low inclination orbits, and in sun synchronous orbits with low orbit-sun angles. In the case of three-axis stabilized, Earth-pointing, geostationary spacecraft for example, these shaded sides are either or both of the north and south main-body panels. In the case of the sun synchronous spacecraft for example, the shaded sides are either or both of the sides or main-body panels that face out along the pitch axis (i.e. that face parallel to the orbit normal and anti-normal). The present invention can also be applied to types of spacecraft, other than geostationary and sun synchronous types, upon which the solar illumination is incident at low angles relative to thermal radiator surface. In those spacecraft it is those main thermal radiator surface that can be shaded by the present invention device.

According to a first embodiment of the invention there is provided a spacecraft for orbiting a sunlit celestial body, the spacecraft including a thermal radiator surface for radiating heat from the spacecraft into space, and a sun-ray blocker device mounted on said spacecraft for shielding said thermal radiator surface from rays of sunlight, characterised in that said sun ray blocker device is locatable for placing in shadow substantially the whole of the thermal radiator surface from sunlight without substantially impeding thermal radiation from said thermal radiator surface into space.

Preferably an effective radiation view factor for thermal radiation from the thermal radiator surface

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(11,12,1804, 2121,2721) to deep space is significantly greater than a corresponding geometrical radiation view factor to deep space, and in particular, for a geostationary spacecraft where the geometrical radiation view factor to deep space is 0.65, the effective radiation view factor to deep space is at least 0.87.

A preferred inventive feature will be seen to reside in the sun ray blocker device including at least one sun blocker panel having a sun-facing surface and an opposed anti-sun-facing surface, wherein the sun-facing surface is thermally insulated from the opposed surface.

Conveniently the sun-facing surface is thermally insulated from the opposed surface by a multi-layer insulation blanket.

Advantageously the sun-facing surface has a low solar energy absorptivity of less than 0.5.

Advantageously the sun-facing surface includes a solar cell panel for supplying electrical power to the spacecraft.

Preferably the sun-facing surface has a high thermal emissivity of higher than 0.7.

A preferred inventive feature will be seen to reside in the sun ray blocker device being moveable between a stowed, non-operative position and a deployed operative position.

Conveniently the sun ray blocker device includes an attachment arm for attaching the sun blocker panel to the spacecraft.

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Advantageously the attachment arm is attached by a hinge means to the sun blocker panel and/or by a second hinge means to the spacecraft.

Advantageously the sun ray blocker device includes a
5 motor for moving the sun ray blocker device between the stowed position and the deployed position.

Preferably locating means are provided for locating the sun ray blocker device with respect to the thermal radiator surface which include adjustment means to
10 maintain the majority of the thermal radiator surface in shadow irrespective of changes in the attitude and/or orbit of the spacecraft.

Advantageously the adjustment means includes carriage means (1801, 1901, 2001) for carrying the sun
15 blocker panel (1800, 1900, 2000) and transport means (1802, 1808, 1903, 1904, 2003, 2006) for moving the carriage with respect to the spacecraft.

Conveniently the transport means includes rail means (1802) and the carriage means (1801) includes drive means
20 to drive the carriage along the rail means.

Preferably the transport means includes an annulus rotatable in circular path defined by bearing means, the annulus being driveable by drive means to move the carriage along the path defined by the bearing means.

Alternatively the transport means includes rail
25 means (1902) and belt means (1903) connected to the carriage means (1901), the belt means being driven by

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drive means (1904) to move the carriage means along the rail means (1902).

Conveniently the adjustment means includes a variable length attachment arm (2101, 2703) for attachment
5 of the sun blocker panel (2100, 2700) to a solar cell array assembly (2103, 2701) for rotation with the solar cell array assembly, such that the distance of the sun blocker panel from the solar cell array assembly may be varied during rotation.

10 Alternatively the spacecraft has a solar cell array adapted for tracking movements of the sun relative to the spacecraft, wherein the adjustment of the location of the sun ray blocker device in relation to the thermal radiator surface is synchronised with the tracking
15 movement of the solar cell array, when in normal operation.

Conveniently the sun ray blocker device is mounted on the solar cell array or on means carry said solar cell array.

20 Advantageously the solar cell array tracks the movement of the sun by rotation of the solar cell array about an axis of rotation of the solar cell array such that the sun blocker panel also rotates about said axis of rotation of the solar cell array.

25 Conveniently the thermal radiator surface is orthogonal to the axis of rotation of the solar cell array so that the sun blocker panel rotates about an axis normal to the thermal radiator surface.

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Advantageously adjustment means includes a variable length attachment arm for attachment of the sun blocker panel to the spacecraft.

5 Advantageously the attachment arm is a scissor arm (2703).

Alternatively the attachment arm (2101) is formed of articulated portions (2104, 2105, 2106) which may be mutually articulated during rotation to vary an effective length of the attachment arm.

10 Conveniently adjustment means for attachment of the sun blocker panel to a solar cell array assembly are such that a distance between the sun blocker panel and the solar cell array assembly may be varied during rotation of the sun blocker panel.

15 Conveniently means are provided for adjusting the size of the sun blocker panel.

Conveniently the spacecraft includes control means for controlling the spacecraft so as to maintain an angle between a sun line and the thermal radiator surface below
20 a predetermined angle by adjustment of the orbit and/or attitude of the spacecraft in use.

Preferably the predetermined angle is 60 degrees.

More preferably the predetermined angle is 45 degrees.

25 Most preferably the predetermined angle is 23.5 degrees.

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Advantageously the control means is adapted to maintain the thermal radiator surface substantially parallel to a plane of an orbit of the spacecraft.

Alternatively the control means is adapted to
5 maintain the spacecraft in a sun synchronous orbit.

Alternatively, the control means is adapted to maintain the spacecraft in an equatorial or low-inclination orbit.

According to another embodiment of the invention
10 there is provided in a three axis stabilised spacecraft for orbiting about a planet and having at least one solar cell assembly having at least one solar cell panel, and being a north solar cell panel assembly or a south solar cell panel assembly, said at least one solar cell panel
15 assembly being mounted on an axle so as to be controllably rotated from said spacecraft about an axis of rotation so as to face the sun, said spacecraft having a nadir panel which is generally pointing to the centre of the planet, an opposite panel known as a zenith panel,
20 which faces away from the centre of the planet and sharing the same planar normal vector as said nadir panel, an east panel and a west panel, said east panel and said west panel having their planar normal vector laying on a orbital plane pointing to the velocity vector
25 of the spacecraft generally tangential to the direction of travel on the orbit, and a north panel and a south panel, said north panel and said south panel having their planar normal vector generally perpendicular to the orbit plane and parallel to the axis of rotation of the planet,

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said solar cell panel extending outwardly from said spacecraft, the improvement which comprises:

attaching at least one sun ray blocker device to said at least one solar cell panel, said at least one device
5 being either a north blocker device or being a south blocker device and corresponding to said at least one solar cell panel, each of said at least one sun ray blocker device being positioned forwardly from and offset relative to a solar cell surface of a solar cell panel
10 and at a predetermined angle to either of said north panel and said south panel, said north panel or said south panel, said sun ray blocker device being positioned so as to cast a shadow on at least a majority of the exposed surface of its corresponding north or south panel
15 during solar exposure thereto.

According to another embodiment of the invention there is provided in a three axis stabilised low inclination orbit spacecraft for orbiting about the earth
20 and having two sets of solar cell array assemblies having solar cell arrays, one set being a north solar array assembly and the other being a south solar array assembly, said assemblies each being mounted on an axle so as to be controllably rotated from said spacecraft
25 about an axis of rotation so as to face the sun, said spacecraft having an earth panel which is generally pointing to the centre of the earth, an opposite panel known as a zenith panel, which faces away from the centre of the earth and sharing the same planar normal vector as
30 said earth panel, an east panel and a west panel, said east panel and said west panel having their planar normal vector laying on an orbital plane pointing to the

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velocity vector of the spacecraft generally tangential to the direction of travel on the orbit, and a north panel and a south panel, said north panel and said south panel having their planar normal vector generally perpendicular to the orbit plane and parallel to the axis of rotation of the earth, said solar cell panel extending outwardly from said spacecraft, the improvement which comprises:

attaching at least one sun ray blocker device to each of said north solar array and said south solar array, one device being a north device and another device being a south device, each of said sun ray blocker devices being in the form of a panel and being positioned forwardly and offset relative to the solar cell surface of a solar ray and at a predetermined angle to said north panel and said south panel, said north blocker device being positioned so as to cast a shadow on at least a majority of the exposed surface of said north panel during solar exposure thereto, and said south blocker device being positioned so as to cast a shadow on the exposed surface of said south panel during solar exposure thereto.

The present invention preferably provides a sun-synchronous sun ray blocker device (not to be confused with sun synchronous orbits referred to elsewhere herein) for use in a spacecraft designed to orbit around a planet with solar incidence at low angles to their thermal radiator surfaces, i.e. with sun directions close to the planes of the individual radiator surfaces. Preferred embodiments of the present invention are spacecraft for operating in an orbit plane oriented at a

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low angle (or within a range of low angles) to the sun direction, the said spacecraft having a thermal radiator surface that is oriented approximately parallel to the orbit plane and a solar array assembly that is rotated
5 about an axis approximately perpendicular to the orbit plane nominally at the orbital rate. Examples of appropriate orbits are: (a) low inclination orbits around the Earth (including nominally equatorial orbits), and
10 (b) sun synchronous orbits with low orbit-sun angles (which around Earth and Mars, for example, are nominally polar orbits). The term "spacecraft" as used herein includes satellites and other space bound vehicles.

Mounted on any spacecraft to which the present
15 invention is applied is at least one device for blocker sun rays and thereby preventing them from directly impinging on a radiator surfaces of the spacecraft.

In many embodiments of the present invention the
20 individual spacecraft will have at least one solar array assembly (comprised of solar cell panels and rotary axial booms) which may be used as mounting support for the sun ray blocker device(s), so that the combination assembly of solar array assembly and sun blocker device(s) is
25 operationally controllably rotated together as an integral unit to track the Sun throughout the orbital revolutions of the spacecraft, said solar array assembly being mounted on the spacecraft so that operationally in orbit it can be rotated about an axis that is maintained
30 oriented approximately perpendicular to the orbit plane in a manner such that the solar-cell side of the solar cell panels is maintained sun facing and substantially

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perpendicular to the Sun direction. Because then the sun ray blocker device may rotate integrally with the solar array assembly, it is able to prevent sun rays from directly impinging on all or part of an associated thermal radiator surface(s), whose plane is maintained approximately parallel to the orbit plane, thus creating a continuous steady and benign thermal environment for the thermal radiator surface.

Spacecraft operated in orbits with low orbit-Sun angles (the angle between the orbit plane and the Sun) are prime candidates for application of the current invention device. Various different frequently-utilized types of orbits feature low orbit-Sun angles. Currently, among the most utilized types of orbits with low orbit-Sun angles are (a) low inclination and nominally-equatorial orbits, including geosynchronous orbits, and (b) the subset of sun synchronous orbits with low orbit-Sun angles. Sun synchronous orbits maintain a little-varying orbit-Sun angle as the planet revolves around the Sun. The Earth revolves around the Sun once per year.

One type of spacecraft operated in a nominally equatorial orbit around a planet, e.g. the Earth, or in particular, a geosynchronous orbit, is frequently used for the purposes of telecommunications, broadcasting, monitoring ecological conditions, global positioning, remote sensing, surveillance and weather forecasting.

Another type of satellite operated in nominally sun synchronous orbits around planets, e.g. the Earth, with low orbit-Sun angles, is frequently used for the purposes

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of weather monitoring and remote sensing of the planet and its atmosphere. Some of the benefits of these sun synchronous orbits are: low spacecraft altitudes, frequent over-flight of the planet within close proximity of virtually all latitudes and longitudes, and near constant angle of solar illumination on the day side of the orbit.

Means of adjusting the attitude and orbit of spacecraft are well known, for example, are described in "Principals of Communication Satelllites" by Gary D Gordan and Walter L Morgan published by John Wiley & Sons 1993, pages 12-14, 55-58 and in "Spacecraft Attitudes, Termination and Control" by James R Wertz published by Kluwer Academic Publishers 1978. Attitude and orbit control may for example be provided by the use of thrusters and/or momentum or reaction wheels.

Typically, the attitude (i.e. the orientation) of these types of satellite is controlled so that as the satellite orbits the planet part of its payload equipment steadily faces approximately toward the center of the planet, while the solar arrays are maintained sun pointing. The attitude (orientation) control systems of such spacecraft belong to various classifications that are well known within the space industry. For example, two of the more currently prominent types of attitude control system are commonly referred to as "three-axis-stabilized" control systems and "spin stabilized" control systems. The present invention device functions independently of the type of attitude control system, and independently of the orientation of spacecraft equipment

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other than the orientation of the thermal radiator surfaces that the device shields from solar energy. In these types of spacecraft, the performance of the present invention device is generally better the closer the
5 shadowed thermal radiator surface is to being parallel to the orbit plane (which in these types of spacecraft is maintainable at a low angle to the sun line).

Hereinafter, the concept of a "model spacecraft" is defined and employed in order to avoid the distraction of
10 multiple lengthy descriptions of diverse spacecraft to which the present invention device may be applied. The model spacecraft is used herein, somewhat like a tailor's dummy, in order to facilitate the illustration and explanation of features, functions, and examples of
15 applications of the present invention device.

By definition the model spacecraft has a basic, deployed (i.e. unfolded), structural configuration that is typical of many current three axis stabilized
20 satellites, and a corresponding operational mode that is typical of a geostationary Earthpointing spacecraft. Note that this definition was selected on the basis of current estimates of the most frequent future application of the present invention device. The definition of the
25 model spacecraft could equally well have been based on typical characteristics of another relevant type of spacecraft, for example an Earth-pointing spacecraft in a sun synchronous orbit with a low orbit-Sun angle.

30 Referring to FIGURES 1 and 5, the basic structural configuration of the model spacecraft is based on a main body in the form of a hollow, right parallelepiped. For

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the stated purposes of using the concept of the "model spacecraft" herein, it is useful to consider the main body as being comprised of six principal, planar, structural panels. The external surfaces of one opposing pair of the six panels that form the main body of the model spacecraft constitute the mounting sites for the thermal radiator surfaces that are shielded from direct solar heating by means of the present invention device. Mounted on one or each of these two radiator-bearing panels, and extending perpendicularly outwards therefrom, is a solar array assembly, comprised of a rotary solar array boom to which are attached solar cell panels.

That is not to say that application of the present invention device is limited to spacecraft resembling the structural configuration and operational mode of the model spacecraft. For example, the present invention device is also applicable to: sun synchronous spacecraft in orbits with low orbit-Sun angles; spin stabilized spacecraft; spacecraft with polyhedral and/or irregular structures; spacecraft that are not nadir pointing; spacecraft with solar arrays that deploy and subsequently lie along axes that are not perpendicular to the radiator-bearing panels; etc.

Much of the text herein that supports the accompanying claims is written with reference to the model spacecraft. Regardless, the supporting text also applies to applications of the present invention device to other suitable types of spacecraft. For example, the principal relevant difference between many suitable sun synchronous spacecraft (for polar orbits at Earth and

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Mars at least, where the polar axes lie close to the planes of sun-synchronous orbits around them) and the model spacecraft is that the plane of the thermal-radiator surface(s) that is shaded by the present invention device is approximately parallel to the axis of rotation of the planet (rather than perpendicular to the axis of rotation of the planet as for geostationary spacecraft like the model spacecraft). Accordingly, the supporting text describing spacecraft like the model spacecraft is easily read as it relates to these suitable sun synchronous spacecraft, for example by substituting in "pitch axis panel" or "orbit normal panel" to replace "north/south panel", and substituting in "velocity panel" or "roll axis panel" to replace "east/west panel".

15 In order to provide functional services in an operational orbit, the model spacecraft has one of the six structural panels of its main body continuously facing the planet, e.g. the Earth. That panel is referred to as the earth panel or the nadir panel. A vector that is outward-from and normal-to the earth panel is parallel to the (body fixed) yaw axis of the spacecraft. In the model spacecraft the yaw axis is maintained nominally parallel to the nadir direction, i.e. is nominally pointed toward the center of the planet. Because the model spacecraft operates in a geosynchronous orbit, which is nominally circular, the yaw axis of the model spacecraft is maintained nominally perpendicular to the velocity vector of the spacecraft. A vector that is outward-from and normal-to the plane of the structural panel opposite the nadir panel is parallel to the negative yaw axis. That main-body panel of three

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axis stabilised Earth pointing geostationary spacecraft like the model spacecraft is usually referred to as the zenith panel or anti-earth panel.

5 Another opposing pair out of the six structural panels comprising the main body of the model spacecraft are oriented so that, nominally or approximately, vectors that are outward-from and normal-to their planes lie in the orbital plane and are perpendicular to the yaw axis
10 and to the nadir and zenith directions. These outward normal vectors are parallel and anti-parallel to the positive and negative (body fixed) roll axes of the spacecraft. Because the geosynchronous orbit of the model spacecraft is circular, the roll axes of the model
15 spacecraft nominally coincide with the velocity and anti-velocity vectors of the orbital motion. For geostationary spacecraft the velocity of the spacecraft is eastward; and consequently these two main-body panels of spacecraft like the model spacecraft are generally
20 referred to as the east and west panels.

 Accordingly, the remaining two structural panels comprising the main body of the model spacecraft are oriented so that their planes are nominally or
25 approximately parallel to the orbit plane. Vectors that are outward-from and normal-to the planes of these panels are parallel to the positive and negative (body fixed) pitch axes of the spacecraft. Since the geosynchronous orbit of the model spacecraft is nominally equatorial,
30 the pitch axes of the model spacecraft are approximately parallel and anti-parallel to the spin axis of the Earth; and accordingly these two main-body panels of spacecraft

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like the model spacecraft are referred to as the north and south panels.

To avoid unnecessary further repetition, to
5 illustrate and explain the features and functions of the present invention device, reference shall be made to application to the (previously defined) model satellite, which is operated in a three-axis-stabilized, Earth-pointing, geosynchronous mode. (That is not to say that
10 application of the present invention device is limited to spacecraft that resemble the previously described model spacecraft and/or are operated in the corresponding mode. For example, the present invention device is also applicable to spin stabilized spacecraft with irregularly
15 shaped structures that are neither nadir pointed nor geosynchronous.)

Through each orbital revolution of a spacecraft like the model spacecraft, which in a preferred embodiment is
20 around the Earth, the Sun sequentially directly illuminates the east, zenith, west, and nadir main-body panels. While illuminated (or insolated) thus these main-body panels absorb incident solar energy and their temperatures increase, which significantly reduces their
25 net radiative cooling capability. If not countered by some means this can significantly limit the quantity of equipment (which dissipate heat into the spacecraft) that can be carried on board, and/or can result in undesirably elevated temperatures of associated spacecraft equipment.
30 The north and south panels, however, generally face deep space during the entire orbit and only directly receive solar illumination and solar energy at relatively low

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incidence angles on a seasonal basis. Because the direct input of solar energy into the north and south panels is relatively low to zero, these panels are the principal sites on spacecraft like the model spacecraft for the locations of thermal-energy radiator surfaces. The north panel is directly heated by the Sun for a duration of about 6 months (from about March 21st to about October 21st) at an incidence angle, defined as the angle between the panel plane and the sun vector, which seasonally increases from 0 degrees (when the sun vector is edge-on to the panel) to about 23.5 degrees followed by a decrease to 0 degrees again while the Sun is on the north side of the earth equator, i.e. during the northern spring and summer. The south panel is directly heated by the Sun for the remainder of the year, i.e. during the southern spring and summer, in a similar fashion and concomitantly with the north panel. These relatively low solar incidence angles favor use of the north and south panels for locating the principal thermal radiator surfaces of the spacecraft. At a maximum incidence angle of 23.5 degrees for the solar vector relative to the north and south panels the incident solar energy is approximately 40% of that for normal (perpendicular) incidence.

25

In the prior art numerous design practices have been employed to the surface treatment of the north and south panels in an effort to reduce the absorbed solar energy, thereby allowing more internal heat dissipation without raising the operational temperature level of the equipment that is thermally coupled to the panels. One example, optical surface reflectors (OSRs), which have a

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high ratio of thermal emissivity versus solar absorptivity, have been widely used as the surface treatment of spacecraft thermal radiators. However, the seasonal solar heating of the spacecraft through OSRs still constitutes a significant amount of heat input to the spacecraft, which forces the spacecraft designer to lower the level of internal power dissipation to maintain an acceptable operating temperature for the spacecraft equipments. Solar energy absorbed by a spacecraft like the model spacecraft through its north and south panels has two obvious undesirable impacts on the performance of the spacecraft.

(1) It reduces the allowable level of internal power dissipation, which directly relates to the "value" of a spacecraft. The revenue from a spacecraft, especially a commercial communications spacecraft, is fundamentally limited by its capacity for power dissipation. A reduced allowable power dissipation level directly results in lower potential for revenue generation, which reduces the value of the spacecraft.

(2) The operating temperatures of the internal equipment are increased, and as a result the reliability of those components may be reduced. The reliability also relates to the life of a spacecraft, which directly relates to its "value" as well.

If the undesired solar heating were to be reduced, higher operational payload power would be allowable within the spacecraft and/or lower operating temperatures of the spacecraft equipments would be achieved.

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Therefore, by virtue of the present invention, the spacecraft could be operated at a higher efficiency, with higher reliability, and would thereby generate revenue at a faster rate, all of which improvements would increase
5 its value.

There is another important factor that affects the capability of a thermal radiator surface to reject heat to deep space: the "effective" radiative view factor
10 (ranging from 0 to 1) from that panel to deep space. The ideal radiative-view-factor enabling a panel to reject maximum heat into deep space is unity (1). A device or means situated between the radiator surface and deep space could block the radiator's view to deep space and
15 thus reduce the heat-radiating capability of the radiator.

The sun ray blocker device of this invention is mounted on the spacecraft, for example conveniently
20 attached to the solar array assembly/assemblies of the spacecraft and rotating therewith. Since the primary function of the sun ray blocker device used in this invention is to provide a significantly more benign thermal environment for the principal thermal radiator
25 surfaces (or panels), basically by shading them, the spacecraft should have at least one such surface. In the case of three-axis-stabilized Earth-pointing geostationary spacecraft, for example, there are two principal thermal radiator surfaces - the north and south
30 panels; and accordingly at least two separate sun ray blocker devices can be included, one to shade each of these panels. Thus, the sun ray blocker device in the

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present invention follows the movement of the Sun with respect to the thermal radiator panel(s) that it shades. In the case of a three-axis-stabilized Earth-pointing geostationary spacecraft, like the model spacecraft for example, the sun ray blocker device casts its shadow onto its associated thermal radiator surface, which is on either a north or a south panel, seasonally - through the six month long northern spring and summer in the case of the north panel, and through the six month long southern spring and summer in the case of the south panel. The (counter-productive) reduction in the radiation-view-factor of the thermal radiator surface caused by the presence of the associated present invention device is small; and the net effect of this reduction combined with the (beneficial) shading of the panel is a great improvement in the radiative efficiency of the radiator surface.

In addition to the foregoing, some of the considerations, advantages and parameters for the present invention device are as follows (others will become self-evident from the subsequent discussion of the FIGURES):

Variety in the operational form and size of the sun ray blocker device is permissible provided that its sun blocker panel follows the movement of the Sun with respect to the spacecraft, and it blocks the Sun's rays by casting a shadow onto the spacecraft main body at appropriate times, and it produces close to the minimum reduction in the effective radiative view factor to deep space of the thermal radiator that it shields, and it

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satisfies other system requirements of the spacecraft
(for example clear field of view requirements).

5 The material and/or the construction of the sun
blocker panel of the sun ray blocker device is preferably
highly thermally insulating between its sun and anti-sun
sides in order to provide the greatest practical
effective radiative view factor and radiative efficiency
of the radiator-surface shielded by the sun blocker
10 panel.

In its fully deployed configuration the sun blocker
panel may be mounted through a wide range of orientations
relative to the radiator surface that it shields (for
15 example, the angle 501 in FIGURE 12a below does not have
to be 90 degrees i.e. a right angle) as long as it casts
shadow providing adequate coverage of the associated
thermal radiator surface(s) on the spacecraft.

20 The ideal width of the sun blocker panel is greater
than either the width or the length of the radiator
surface that it shields. However, the dimensions of the
sun blocker panel may be limited by other constraints.
For example, in the launch configuration the folded
25 dimensions of the sun blocker panel may be limited by
launch-envelope constraints, i.e. the size of the volume
allowed for the spacecraft by the launch vehicle during
launch. Therefore, it may be necessary to make the sun
ray blocker panel deployable to enable it to be folded
30 for launch and deployed in orbit. This can be achieved by
hinged deployment, slide extension, pre-offset or any
other means to increase the width of the sun blocker

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panel (see FIGURES 16a, b and c, and 17a, b and c discussed below).

5 The mechanisms for extending, deploying, and
supporting the sun blocker panel may involve various
techniques and devices that are well known in the current
state of the art of the design of mechanisms for
spacecraft. For example the techniques and devices
employed could involve mechanisms constructed from well
10 known device types such as: hinges, flaps, slides, spring
motors, wax motors, detentes, cable/bolt cutters, split
nut releases, pin pullers, hook and pin releases, etc.
Alternatively, so-called "active" devices such as
electrical motors may be used at the discretion of the
15 spacecraft designer. For example, one or more electrical
motor (for example a stepper drive motor) could be
employed to produce the motions resulting in extension
(and possibly also retraction) of the sun blocker panel.
Such active control could be utilized to facilitate
20 certain operations of the spacecraft, for example
station-keeping and attitude control operations for which
displacing the sun blocker panel from the exhaust plume
fields of rocket thrusters would be beneficial.

25 The present invention device is applicable to
spacecraft other than those spacecraft, like the model
spacecraft for example, which operate in the low-
inclination or equatorial orbits that have been described
thus far herein. It is applicable to the broad class of
30 spacecraft for which the solar illumination (insolation)
is incident at low angles relative to the planes of the
surface(s) of their thermal-radiator surface(s).

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A certain subset of spacecraft belonging to the set of spacecraft that are well known in the space industry as "sun synchronous" fulfill this requirement for low solar incidence angles on at least one thermal radiator surface; and the present invention is applicable to them. Within this subset of sun synchronous spacecraft is an even smaller but well known subset comprised of those spacecraft that operate in orbits with low orbit-Sun angles and in which the thermal radiator surfaces are utilized while oriented close to parallel to the orbit plane. A sun ray blocker device according to this invention is applicable to those spacecraft, to provide them with a shaded, benign, and desirable thermal environment for their thermal-radiator surfaces basically by protecting them against direct solar heating. Note, however, that when the angle of incidence of direct sunlight on the thermal radiator surface is zero the sun ray blocker device is unnecessary.

20

Heretofore the structural configuration and orientation of spacecraft to which the current invention device is applicable have mainly been described with reference to three-axis-stabilized Earth-pointing spacecraft for operating in low inclination or equatorial orbits, like the model spacecraft for example. The fundamental difference between those preceding descriptions and the structural configurations and orientations of the sun synchronous spacecraft to which the current invention device is applicable stems from the orientation of the orbit with respect to the axis of rotation of the planet. Within the space industry, sun

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synchronous orbits are widely referred to as being "polar", since the orbit plane of a sun synchronous orbit, around Earth and Mars at least, lies within several degrees of the axis of rotation of the planet; and therefore nominally includes the planetary poles. Therefore, for the aforementioned particular subset of sun synchronous spacecraft to which the current invention device is applicable, the panels and the radiator surfaces on them that are thermally protected by the current invention device are generally not, strictly speaking, "north" and "south" panels. However, herein the terms "north" and "south" are occasionally used for convenience to indicate the panels that are thermally protected by the sun blocker panel on spacecraft in sun synchronous orbits as well as on spacecraft like the model spacecraft, for example, in (nominally) equatorial orbits. The rationale is that in the particular, suitable, well known, and currently populous, aforementioned, subset of sun synchronous spacecraft the planes of thermal radiator panels shielded by the present invention device are also approximately perpendicular to the axis of the orbit (as for spacecraft like the model spacecraft in its orbital configuration and orientation). For both these types of spacecraft we could instead meaningfully refer to the protected panels and radiator surfaces as "pitch-axis" or "orbit normal" panels and surfaces, because the pitch axis of the spacecraft (which is parallel to the orbit normal) is nominally/approximately perpendicular to them and thereby defines their orientation.

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Depending upon the requirements of the propulsion subsystem and/or the attitude control subsystem of the spacecraft, the spacecraft designer may elect to provide only one sun ray blocker device, i.e. on only one of the two sides of the spacecraft that face approximately along the pitch axis (e.g. on the north or the south panel for the model spacecraft). In any particular application there may be a preference for one side of the spacecraft over the opposite side because of other system requirements. For example, in a potential embodiment of the present invention device on a particular current design of geostationary spacecraft, the south side is preferred because of field of view requirements for attitude-control thrusters on the north side.

Again, if the spacecraft designer elects to do so, solar cells can be mounted onto the external surfaces of the sun blocker panel to provide additional power to the spacecraft.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention should be more fully understood when the specification herein is taken in conjunction with the drawings appended hereto showing exemplary embodiments of the invention wherein:

FIGURE 1 is a simplified perspective view of a prior art three axis stabilized Earth-pointing geosynchronous spacecraft;

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FIGURE 2 shows an east-panel based view of the prior art spacecraft illustrated in FIGURE 1 orbiting in a low inclination or an equatorial orbit;

5 FIGURE 3a shows a north-panel based, top view of the prior art spacecraft illustrated in FIGURE 1 orbiting about the Earth at different times of the day, and FIGURE 3b illustrates orbit-plane based views of that spacecraft at its noon, 6 a.m., and midnight positions and also
10 establishes sun angles for different seasons of the year;

FIGURES 4a and 4b show the variation in the solar incidence angle on the north and south panels, respectively, of the prior art spacecraft illustrated in
15 FIGURE 1 orbiting Earth, through one calendar year;

FIGURE 5 illustrates a perspective view of a spacecraft configuration according to the present invention, based on the prior art spacecraft illustrated
20 in FIGURE 1;

FIGURES 6a, 6b and 6c illustrate top views of a present invention arrangement as applied to the prior art spacecraft illustrated in FIGURE 1. The views shown are
25 simultaneously parallel to both the orbit-plane and the plane of the solar cell panels and the sun blocker panels of the sun ray blocker device. Hereinafter this view direction is also referred to as "top view". FIGURES 6a, 6b and 6c show that as the spacecraft revolves around the
30 orbit the earth panel always faces the Earth, and the cell-side of the solar array panels together with the

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front (sunward) sides of the sun blocker panels of the sun ray blocker devices always face the Sun;

FIGURES 7, 8 and 9 illustrate top views of present invention devices utilizing different attachment arrangements;

FIGURES 10a, 10b and 10c illustrate portions of top views of one of the solar array assemblies of a prior art spacecraft before, during, and after its deployment;

FIGURES 11a, 11b, 11c, 12a, and 12b show, in top view, aspects of the deployment and the function of present invention devices as applied to the prior art spacecraft shown in FIGURES 10a, 10b, and 10c;

FIGURES 13 and 14a show partial top views of two alternative present invention devices; and FIGURE 14b shows a partial back (anti-sun) side view of the arrangement shown in FIGURE 14a;

FIGURES 15a and 15b show partial top views of an alternative present invention device in its fully deployed and partially deployed configurations, respectively;

FIGURES 16a, b, and c show a view of an alternative present-invention device from the front (sunward) direction with the sun blocker panel fully deployed, and two views from a direction orthogonal to both the front view and the (previously defined) top view directions

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with the sun blocker panel folded and deployed,
respectively;

FIGURES 17a, b, and c show a different alternative
5 present-invention device in the same views and deployed
states as those shown in FIGURES 16a, b, and c;

FIGURE 18 shows a further embodiment of the
invention;

10

FIGURE 19 shows another embodiment of the invention;

FIGURE 20 shows another embodiment of the invention;

15 FIGURES 21 to 24 and 26 show another embodiment of
the invention;

FIGURE 25 shows details of the embodiments of
FIGURES 21 and 24 and 26;

20

FIGURES 27 to 30 show another embodiment of the
invention; and

FIGURES 31 and 32 illustrate alternative shapes for
25 sun blocker panels used in the present invention.

Referring now to FIGURE 1, there is shown an oblique
view of a fully deployed (i.e. fully unfolded from its
launch configuration) spacecraft (or satellite) 1, like
30 the previously described model spacecraft for example,
which is represented by a main body 10 which contains six
external panels: 11, 12, 13, 14, 15 and 16, a group of

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antenna reflectors 20, 21, 22 and 23, and two solar array assemblies, consisting of two solar arrays (one or more solar cell panel) 100 and 101 and their supports 100a and 101a by which they are connected to the main body 10, which are extended northward and southward from the main body out of the north and south panels 11 and 12, respectively. The number of antenna reflectors is driven by the need of the telecommunications application and is a matter of design. In this example, four reflectors are shown and are represented by two deployable large reflectors 20 and 21 mounted on east and west panels 15 and 16, respectively. Two non-deployable reflectors 22 and 23 are mounted on nadir panel 14. While orbiting in a low inclination orbit about Earth, the spacecraft is controlled in such a way that the earth or nadir panel 14 is pointing in the general direction of the center of the Earth, thus allowing the antenna reflectors to perform telecommunications functions with Earth. Opposite to the earth panel 14 is the zenith panel 13.

20

The solar arrays 100 and 101 may contain multiple panel elements (typically two to eight or more on each side - a four panel-element example is shown in FIGURE 1) or may contain as few as one panel element. However, usually solar arrays that are comprised of multiple solar cell panels are utilized, in order to provide sufficient electrical power for the spacecraft's use. The size and number of the solar cell panels is driven by mission power requirements, and is constrained by, among other factors, the capability of the attitude control subsystem to maintain pointing stability and also by the capability of the thermal control subsystem to manage the heat

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dissipated on board the spacecraft. Once the size and number of the panel elements is defined, generally it is desired to maximize the electrical power generated by the solar cells which are mounted on one side of the array panels by facing the cell side of the array toward the Sun as directly and as long and continuously as possible. With spacecraft main body 10 maintaining its earth panel 14 pointing to the Earth continuously, the line between the spacecraft and the Sun will cone around the north-south axis of a spacecraft like the model spacecraft once every orbit, making the Sun appear to circle about the main body 10 as it does so. In order to maintain both solar arrays of a spacecraft like the model spacecraft pointing directly to the Sun they are driven by motor systems which rotate the arrays about the north-south axis, as indicated by the arrow R in FIGURE 5 with respect to the main body 10 at a speed such that the cell side of the array always faces the Sun while the spacecraft orbits the Earth, i.e. the solar arrays rotate about the north-south axis sun synchronously with the Sun to achieve optimum sun exposure for maximum power generation.

Reference is made to FIGURE 2, a top view of prior art spacecraft or satellite 1 of FIGURE 1, wherein the aforesaid seasonal exposures are illustrated. (Parts identical or very similar to those in FIGURE 1 are identically numbered throughout the FIGURES herein and are not all repeated, to reduce redundancy. This applies to all of the following FIGURES that illustrate the same spacecraft or the same parts or components, or ones very similar.) The north panel 11 and the south panel 12

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(FIGURES 1 and 2) are maintained oriented parallel to the orbital plane of the satellite, which is co-planar or nearly co-planar with the equatorial plane of the Earth. While the spacecraft is orbiting the Earth, these panels (11 and 12) will not receive daily solar input like the other panels (earth panel 14, zenith panel 13, east panel 15 and west panel 16). Those two panels 11 and 12, however, will be subjected to direct solar heating on a seasonal basis, at incidence angles which will peak at 23.5 degree at the northern summer- and northern winter-solstices respectively, as shown.

FIGURE 3a shows a north-based top view of a spacecraft 1 orbiting Earth at different local times of day and illustrates the constancy with which the nadir panel 14 faces Earth 300 throughout the orbital revolutions. (The solar cell panels are shown edge-on out of the paper.)

FIGURE 3b shows a partial side view of the spacecraft 1 of FIGURES 1 and 2 at midnight, 6 a.m., and noon orbital positions, and also the approximate sun angles at the northern summer and northern winter solstices at midnight and noon.

FIGURES 4a and 4b show the profile of the solar incidence angle on the north and south panels, respectively, such as panels 11 and 12 of spacecraft 1 shown in FIGURE 1, for one calendar year.

It can be seen from FIGURES 4a and b that sunlight is incident on each of the north panel and south panel

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for a portion of the calendar year. These periods are nominally 21 March through 21 September for the north panel, and 21 September through 21 March for the south panel. Therefore, the sun ray blocker devices of the
5 current invention perform their shading functions for their respective radiator panels for those periods only.

FIGURE 5 illustrates one preferred embodiment of the current invention, which eliminates or greatly reduces
10 the seasonal solar input on the north and south panels 11 and 12, thus providing more efficient thermal radiators for the spacecraft.

In this present invention embodiment, the sun ray
15 blocker devices are comprised of two sun blocker panels 111 and 112 and mounting, supporting, and deployment mechanisms by means of which the blocker panels are integrated with and deployed with the structures and mechanisms that support and cause the solar array to
20 rotate. The radiators on the north and south panels 11 and 12 have dedicated sun ray blocker devices 111 and 112 attached to the north and south array assemblies 100 and 101, respectively, as shown in FIGURE 5. After the thus modified spacecraft 1 has been launched into the
25 operational orbit and its appendages have been fully deployed, the sun blocker panels 111 and 112 will achieve their final positions in front of the cell side of the solar arrays with their surfaces more or less parallel to the plane of the solar arrays. The south blocker device
30 112 is positioned such that during the time between the northern autumnal and northern spring equinoxes, when otherwise there would exist a potential for solar heating

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of the south panel 12, the south blocker device 112 will cast a shadow over the south panel 12 thereby eliminating the potential for such solar heating. The north blocker device 111 performs a similar function relative to the
5 north panel 11 during the time between the northern spring and northern autumnal equinoxes. When the solar array assemblies 100 and 101 are maintained directly sun pointed, by virtue of their being rotated, the sun blocker devices will likewise be maintained directly sun
10 pointed and thereby interposed between the Sun and the north and south panels that they shade.

The materials used for the sun blocker panels 111 and 112 are selected to minimize the heat transferred
15 from their sun facing surfaces 111a and 112a to their anti-sunward surfaces 111b and 112b. This may be achieved by including insulating material(s) and constructions in the composition of the sun blocker panels. For example, the panels may include known thermally insulating
20 materials and assemblies of materials, such as multi-layer insulation (MLI) blankets which utilize layered films of metallized Mylar separated by fabric netting. These materials and constructions are well known in the space industry and have typical heat resistance values of
25 0.007 to 0.01 Watt/deg.C/sq.in. The sun blocker panels of the present invention device will generally experience a sizable temperature difference, for example possibly greater than 100 degree C, between surface 111a and surface 111b and between surface 112a and surface 112b
30 when the satellite is in its normal orientation in the mission orbit, except when the spacecraft is passing through the Earth's shadow.

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To obtain the maximum sun blocking effect, the panels of the sun ray blocker devices 111 and 112 are configured (sized, oriented, and positioned) in such a way that at the summer and winter solstices, when the Sun is about 23.5 degree from the orbit plane, the sun blocker devices will cast shadows that entirely cover the radiator surfaces on their respective thermal radiator surfaces on the spacecraft panels 11 and 12. Accordingly, if the radiator surfaces are rectangular the shadows must be at least as wide as the diagonals of the rectangles.

FIGURES 6a, 6b and 6c show top partial views of a present invention arrangement as the spacecraft orbits Earth and the main body 10 is rotated at the orbital rate so that the earth panel 14 always faces Earth, and the sun blocker panels 111 and 112 always face the Sun (which is at the left in the FIGURES). These FIGURES are drawn in the inertial frame of reference of the solar array assemblies 100 and 101. Thus, if one were to stand on either of the solar array assemblies 101 and 102 one would see main body 10 rotate one revolution per orbital revolution around the Earth.

FIGURE 7 is a top partial section view showing more details of a present invention spacecraft. In this context the phrase "top view" denotes a view parallel to the planes of the sun blocker panels 111 and 112 and also parallel to the orbit plane. Note that in Figure 7 through Figure 15b various examples of embodiments of the present invention are depicted together with generic

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partial views of a spacecraft main body and a solar array assembly (labeled 400 and 408, respectively, later in FIGURES 10 and FIGURES 11). Additionally, FIGURES 8 and 9 show alternative embodiment arrangements in top partial section views.

In FIGURE 7, the spacecraft has main body 10, north panel 11, and solar cell panel support 223 with attached solar cell panel 225. In this case, there is a connecting solar array boom-and-yoke 219 and hinges at hinge points 221 and 227. Together this solar cell panel support 223, a solar cell panel 225, a solar array boom-and-yoke 219, and the hinges at hinge points 221 and 227 comprise part of a solar array assembly. The solar array boom-and-yoke 219 fold forwardly against north panel 11 and the solar cell panel support 223 together with the solar cell panel 225 folds down at hinge point 227 in an accordion-like fashion for launching. During launch, ascent, and orbit achievement the solar array assembly is in its folded-closed configuration. After achievement of the mission orbit it is electro-mechanically and/or mechanically deployed (unfolded) to allow the solar cells to be maintained directly sun-pointed. Attached to solar cell panel support 223 is a two-section connecting arm having a short inner portion 209 and an outer portion 207 connected by hinge(s) at hinge point 215. The anti-sunward side 111b of sun blocker panel 111 is connected to outer arm portion 207 by hinge(s) at hinge point 203. Optional solar cells 201 are functionally positioned on the sunward surface 111a of the sun blocker panel 111. Hinge points 203 and 215 provide for folding of the solar blocker panel 111 and its hinged arm 207 against the

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solar cell panel 225 in a compact and stiff configuration suitable for launch and subsequent deployment. The electromechanical and/or mechanical designs and methods for deploying (opening) and closing solar array assemblies are commonly used in contemporary spacecraft. The same or similar mechanisms are used to deploy the sun ray blocker devices of the present invention. These mechanisms and methods for deployment and closing are well within the skills of the artisan.

10

In FIGURE 7, there is an imaginary plane 250 extending off the surface of north panel 11. In its deployed configuration the sun blocker panel 111 may touch or extend through this imaginary surface, and consequently may provide additional shading for the earth, west, zenith and east panels as they rotate with respect to the Sun.

FIGURE 8 shows an alternative embodiment where sun ray blocker device 271 does not intersect imaginary plane 250. Further, it has a single connecting arm 205 with hinge points 203 and 217 at opposite ends to form an assembly and is connected directly to the substrate of solar cell panel 225. It may be folded and stowed for launch and deployed or unfolded in orbit in a similar way to the sun ray blocker device in FIGURE 7. In FIGURES 7 and 8, the sun ray blocker devices cast their shadows over the major part of the outer surface of north panel 11 and, in these embodiments, completely shadow that surface during the times when otherwise they would be exposed to the Sun. Further, the solar cells 201 may be

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included to produce additional solar power for the spacecraft.

In FIGURE 9, identical parts to FIGURES 7 and 8 are
5 identically numbered. Sun ray blocker device 301 is
connected directly to solar cell panel support 223 by
hinge(s) at hinge point 309 so as to fold over up-close
against solar cell panel 225 in the launch configuration.
In this embodiment, sun ray blocker device 301 is not
10 parallel to the solar array, yet still effectively shades
north panel 11.

FIGURES 10a, 10b and 10c depict a typical prior art
sequence of deployment of a solar array assembly, which
15 is part of the transformation of the spacecraft from its
launch configuration to its configuration for normal
operations in orbit. For simplification in this
document, only one (the north) solar array assembly is
shown in the FIGURES. These particular FIGURES show a
20 satellite with a main body 400, and a solar array
assembly 408 comprised of four solar cell panels, with
solar cell surfaces 400a, mounted on solar cell panel
supports 408 which are interconnected by hinges at three
hinge points 403, 404, and 405 and connected to the main
25 body 400 by a single boom 419 and hinge(s) at hinge
points 401 and 402. FIGURE 10a depicts the solar array
assembly folded and stowed for launch. FIGURE 10b
depicts it in the process of being deployed (unfolded).
Figure 10c depicts its fully deployed state. If a
30 multiple-arm boom design is desired by the spacecraft
designer, various embodiments can be designed to satisfy

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performance requirements using greater numbers of arms and hinge points.

FIGURES 11a, 11b and 11c illustrate the deployment sequence of one possible design embodying the present invention. Components in FIGURES 11a, 11b, and 11c that are identical to components in FIGURES 10a, 10b, and 10c are numbered identically to their identical parts. In addition to the prior art solar array assembly that was previously depicted in FIGURES 10a, 10b and 10c, FIGURES 11a, 11b, and 11c also depict the present invention sun blocker panel 411 connected to the solar array boom 419 by an arm 430 and hinges at hinge points 406 and 407. Alternatively, by design the sun blocker panel 411 could be hingedly attached via the arm 430 to a convenient different location on the solar array assembly. FIGURE 11a depicts the solar array assembly and the sun ray blocker device folded and stowed for launch, FIGURE 11b shows them partially deployed (unfolded). FIGURE 11c depicts their fully deployed state. FIGURES 12a and 12b show sun blocker panels which are not parallel to the plane containing the solar cell panels yet which still provide proper shading of the north or south panel. Components in FIGURES 12a and 12b and subsequent figures that are identical to components that appear in previous figures are numbered identically with their corresponding or very similar components or are left un-numbered to avoid unnecessary repetition. Alternatively, by design the sun blocker panel 111 could be hingedly attached via the arm 430 to a convenient different location on the solar array assembly.

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FIGURE 13 depicts yet another alternative embodiment of the present invention. The sun blocker panel 511 is connected to the solar array boom 219 by hinge(s) at hinge point 507 for its stowing folded and subsequent deployment.

FIGURES 14a and b show an arrangement similar to that in FIGURE 13, with identical parts identically numbered, however, more hinges at hinge points 606 and 607 are used with blocker panel 611 as required by design for folding the panels prior to deployment.

FIGURE 14b represents a partial view of the anti-sun side of the spacecraft looking toward the Sun (i.e. a side view relative to the top view shown in Figure 14a).

FIGURES 15a and 15b show one embodiment in which sun blocker panel 811 utilizes separate active motors 306 and 307 which are used to actively deploy and/or retract the sun ray blocker device. This arrangement allows satellite operators to use deployment motors that are separate from the solar panel deployment motors so as to permit them to retract the sun blocker panels to prevent their interference, if any, in satellite operations such as in the use of propulsion systems during spacecraft performance of station keeping or attitude control maneuvers.

In some spacecraft designs the required size (dimensions and/or area) of a sun blocker panel in its fully deployed configuration may exceed the constraints of its "launch envelope" i.e. the constraints of the

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maximum-allowable space allocated to the sun ray blocker device in the launch configuration of the spacecraft when the solar array and the sun ray blocker device are in their launch configuration. Therefore, for compatibility with the constraints of the size of the corresponding launch envelope it may be necessary for the sun blocker panel of the sun ray blocker device to be comprised of several (i.e. more than one) pieces, instead of being one single integral piece, which are folded together in the launch configuration and are subsequently deployed (unfolded) in orbit to form effectively one continuous sun blocker panel. FIGURES 16a, 16b and 16c, and FIGURES 17a, 17b and 17c, respectively depict two examples from the many possible designs for sun blocker panels which fold and deploy. Parts a, b, and c of the FIGURES 16 and 17 show each of the two designs in a view from the front (Sun) direction with the sun blocker panel fully deployed, and two views from a direction orthogonal to both the front view and the top view directions with the sun blocker panel folded and deployed, respectively. (As defined earlier herein the phrase "top view" denotes a view that is simultaneously parallel to the plane of the sun blocker panels 921 or 951 and the orbit plane.) This allows the sun ray blocker device to increase its dimensions using hinge(s) and/or strut(s) and/or flap(s) etc. at hinge points 925 and 927 or a slide-out design. Referring collectively to all FIGURES 16, sun blocker panel 921 has a center section 923 with hinge(s) and/or strut(s) and/or flap(s) etc. at hinge points 925 and 927 and outer, swing up panels 929 and 931 which may be designed to deploy (swing up) automatically. In all FIGURES 17, sun blocker panel 951 has main section 953

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with slide-out extensions 955 and 957 that may be designed to deploy (slide out) automatically. (Automatic hinging and automatic sliding or telescoping is well within the purview of the artisan in the spacecraft industry and need not be further elaborated upon herein.)

The embodiments of the present invention device illustrated in FIGURES 18 through FIGURE 30 are as generally applicable as the other embodiments described herein. However, they also function efficiently in cases where a sun blocker device cannot be attached to an axle located near the center (1811, 2123, 2722) of an associated thermal radiator surface (1804, 2121, 2721).

One such case is that in which the axis of rotation (1803, 2131, 2701) of a solar array assembly extends outward from the associated thermal radiator surface (1804, 2121, 2721) at a location that is significantly offset from the center (1811, 2123, 2722) of the thermal radiator surface. In that case, designs with an attachment arm of fixed length between the sun blocker panel and the solar array axis could be unsuitable, because the motion of the sun blocker panel about the center of the thermal radiator surface would be eccentric.

Another such case is that in which there are stay-out zones inboard of the periphery of the associated thermal radiator surface - through which objects such as a supporting boom (for example for a sun blocker panel) are not allowed to pass. This could be the case, for example, when certain attitude- or orbit- control

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thrusters (1810) are also located on the panel upon which the thermal radiator surface (1804) is located.

The arrangements illustrated in FIGURES 18 through
5 FIGURE 30 may be employed to overcome these constraints, whilst still maintaining a sun blocker panel at a substantially uniform distance from the center of the associated thermal radiator surface. Selection between
10 the embodiments shown in FIGURES 18-30 for any particular application may involve trade-offs between many additional performance-requirements of the spacecraft-system, including for example: mass, strength, stiffness, flatness, circularity, simplicity, and reliability.

15 Figure 18 shows an embodiment of a sun blocker device in which the sun blocker panel 1800 is mounted on a carriage 1801 with wheel-sets or bearing-sets 1808 and 1830 by means of an attachment arm 1805 in which the carriage may be driven around a closed rail 1802, the
20 carriage 1801 being attached to the rail 1802 by rolling or sliding means that also react against and thereby limit rotations of the carriage 1801 (and thereby the sun blocker panel) about axes passing through the points of contact of the carriage and the rail. In one of many
25 potential embodiments, for example, this may be achieved using wheel or bearing sets 1808, 1830 that are adequately spaced both along-track and cross-track on both sides of the rail 1802, and which are also cambered at an adequate angle to the plane of the baseplate.
30 Attached to the carriage is at least one generally-radial boom or strut 1805, an outer end of which is attached to the sun blocker panel at hinge point 1812 and an inner

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end of which is attached to the carriage 1801 at hinge-point 1813, and the carriage is rollingly or slidingly mounted on the rail 1802 by the wheels or bearings 1808 and 1830. At least one of these wheels 1830 or bearings is provided with a motor to drive the carriage along the rail 1802, for example by friction, or by the engagement of a toothed wheel or a worm-drive in a rack. Electrical power may be supplied to the motor, via brushes for example. The attachment arm 1805 and the sun blocker panel 1800 can be folded at the hinge points 1812 and 1813 to achieve a stowed configuration of the sun blocker device for launch, during which the folded device may be temporarily caged securely for proper management of launch-induced dynamic environments and loads. The sun blocker panel may be further folded for launch as illustrated in FIGURES 16 and 17. Following launch the attachment arm 1805 and the sun blocker panel 1800 can be deployed for subsequent operation in orbit, including sun-tracking travel around rail 1802. It will be appreciated that the rail 1802 need not be circular as shown in FIGURE 18, but in the case of a significantly rectangular thermal radiator surface, for example, the rail could be elliptical and in either case may be diverted to avoid obstacles mounted on the spacecraft.

Alternatively, as illustrated in FIGURE 19 the attachment arm 1805 could be mounted on a solid rotatable wheel instead of on a carriage and rail. In the embodiment illustrated in FIGURE 19 the wheel is a ring or annulus 1902 floating in circumferentially located bearing-sets 1903 and controlled and driven by a motor 1930 mounted on the baseplate under 1804.

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In a similar alternative embodiment, illustrated in FIGURE 20, a carriage 2001, similar to that provided in the embodiment illustrated in FIGURE 18, is provided; but
5 in this embodiment the carriage 2001 is driven around a closed rail 2002 not by a motorized wheel, but by an endless belt 2003, chain, or cable attached to the carriage 2001, the belt being driven by a motor 2030 that is mounted to the baseplate under 1804 and which engages
10 the belt 2003, chain, or cord. A tensioning device 2040 is also provided to engage the belt 2003 and tension the belt while not impeding the passage of the carriage around the rail 2002. Again, as in the embodiment illustrated in FIGURE 18 the rail 2002 need not be
15 circular.

Figures 21 through 30 illustrate embodiments in which a sun blocker panel is mounted on the spacecraft via an attachment arm from an axis 2131, 2701 that is
20 offset from the center 2123, 2722 of an associated thermal radiator surface. The axis 2131, 2701 could be concentric with or identical to the axis of rotation of a solar array assembly.

Figures 21 through 26 illustrate an alternative
25 embodiment in which a sun blocker panel 2100 is attached to an axle at axis 2131. The axle may be either concentric with or identical to an axle of a solar array assembly. The sun blocker panel is attached to the axle
30 by an articulated attachment arm 2130 that included three articulated portions 2132, 2134, 2137.

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The inner end of the inner-portion 2132 is fixed radially to the axle at axis 2131. The middle-portion 2134 is pivoted at its inner end to inner-portion 2132 at pivot-point 2133, and the outer end of middle-portion 2134 is pivoted to the inner end of outer-portion 2137 at pivot point 2135. At its outer end the outer-portion is attached to the sun blocker panel at hinge point 2138 and near its inner end the outer-portion is hinged at hinge point 2136 to allow folding and stowing for launch followed by deployment in orbit.

As depicted in FIGURE 21 through FIGURE 26 the inner-portion 2132 and the outer portion 2137 of the attachment arm 2130 turn anti-clockwise at the same rate, the outer-portion 2137 carrying the sun blocker panel with it, whereas the middle portion 2134 rotates clockwise at the same rate.

The length of the inner-portion 2132 is approximately equal to the offset of the axis of rotation 2131 from the center 2123 of the thermal radiator surface. In principle the length of the middle-portion 2134 may be longer or shorter than the length of the inner portion 2132. However, in the case that the axis of rotation 2131 is occupied by an obstruction such as the axle of a solar array assembly then the middle-portion 2134 must be shorter than the inner-portion 2132 for clearance of the solar array axle at axis 2131, as can be seen in FIGURE 23 in which the attachment arm 2130 is approaching its closest to the axle at axis 2131.

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By articulating the articulated portions through rotation of the arm 2130 about the axis of rotation 2131 the sun blocker panel can be maintained at a substantially constant distance from the center of the associated thermal radiator surface 2121, to describe a substantially circular path 2140 around the spacecraft. It will be evident that in the case of a thermal radiator surface that is significantly far from being radially symmetric the length of the articulated portions of arm 2130 could be adapted to achieve a wide range of desired paths around the thermal radiator surface.

As shown in FIGURE 21, the articulated portions 2132, 2134, 2137 are arranged to the full reach of attachment arm 2130 in a straight line when the sun blocker panel is passing a side of the thermal radiator surface furthest from the axis of rotation 2131. As shown in FIGURES 22 and 23 the attachment arm 2130 has an effective length equal to the sum of the lengths of an outer 2137 and an inner 2132 articulated portion when the sun blocker panel 2100 is at an intermediate distance from the axis of rotation 2131. As shown in FIGURE 23, the effective length of the attachment arm 2130 is at its minimum when the sun blocker panel is at its closest to the axis of rotation 2131, at which point its length is equal to the sum of the lengths of the inner 2132 and outer 2137 portions less twice the length of the middle-portion.

The inner articulated portion 2132 of the attachment arm 2130 rotates about axis 2131. The means of attachment of the inner articulated portion 2132 may be

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independent of a solar array axle along axis 2131, the inner portion 2132 then being mounted to a concentric tubular axis around a central solar array axle. Alternatively, the inner articulated portion may be fixed
5 solidly to a solar array axle along axis 2131.

In the illustrated embodiment, for a geostationary spacecraft for example the inner and outer articulated portions rotate anti-clockwise at one revolution per day, and the middle articulated portion rotates clockwise at
10 one revolution per day. This rotational relationship may be achieved by diverse means, such as: separate motorized pivots at pivot points 2131, 2133, and 2135; or by a system of belt-linked pulley wheels at pivot points 2131,
15 2133 and 2135, driven by a single motor or by an axle along axis 2131.

The articulated portions 2132, 2134, and 2137 may be sprung together, so that in a failure mode the attachment
20 arm 2130 automatically extends to its greatest length. In that case, any failed pivot points can be made to fail free, for example using commandable frangible-links in the associated pulley wheels or drive motor, allowing spring-driven extension of the arm 2130.

25 FIGURES 25 and 26 illustrate a means of articulating the articulated portions 2132, 2134, 2137 with respect to each other, utilizing a driving force from a solar array axle at axis of rotation 2131. A cylinder 2501 is
30 provided, mounted co-axial with the solar array axle at axis 2131 but fixed to a base panel 2121. The inner articulated member 2132 is fixed to the solar array boom

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at axis 2131 so that the inner articulated member 2132 rotates at the same rate as the solar array boom at axis 2131. A middle articulated portion 2134 is pivotally fixed to an outer end of the inner articulated portion 2132 at a pivot point 2133 and a pulley wheel 2502 of the same diameter as cylinder 2501 is fixed to an inner end of the middle articulated portion 2134. A toothed belt 2506 is looped around the cylinder 2501 and the pulley wheel 2502 so that as the solar array shaft 2131 and the inner articulated portion 2132 rotate anti-clockwise in a direction of the arrow 2507, the toothed belt 2506 causes the pulley wheel 2502 and the middle articulated portion 2134 to counter-rotate at the same rate in the direction of arrow 2508.

As shown in FIGURE 26, a second equal sized pulley wheel 2601 is fixed to an outer end of the inner articulated portion 2132 on a side of the inner articulated portion 2132 opposite to that on which the cylinder 2501 is fixed to base panel 2121, and a third equal sized pulley wheel 2602 is fixed to an inner end of an outer articulated portion, such that the third pulley wheel 2602 and the outer articulated portion 2137 are together pivotally attached to the outer end of the middle articulated portion 2134. A second toothed belt 2603 loops around the second pulley wheel 2601 and the third pulley wheel 2602 so that as the middle articulated portion 2134 rotates in the direction of arrow 2508 the toothed belt 2603 causes the outer articulated portion 2137 and the third pulley wheel 2602 to counter-rotate at the same rate in the direction of arrow 2604. Thus, the outer articulated portion 2137 rotates in the same sense

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as the inner articulated portion 2132 whereas the middle articulated portion 2134 counter-rotates.

In a further embodiment illustrated in FIGURES 27
5 through 30, a sun blocker panel 2700 is attached to an axle 2701 of a solar cell array by means of a scissor attachment arm 2730. The scissor arm is comprised of a first articulated arm 2704, 2708 and a second articulated arm 2705, 2709, comprised of inner articulated portions
10 2704, 2705 and outer articulated portions 2708, 2709 respectively. The inner articulated portions are connected by hinges at hinge points 2702, 2703 to the solar array boom 2701 respectively and the outer ends of the outer articulated portions 2708, 2709 are connected
15 by hinges 2710, 2711 to the sun blocker panel 2700 such that when the articulated arms are extended to the full length they are still not parallel to avoid their locking up. A lanyard 2712 is located in between the articulated arms 2704, 2708 and 2705, 2709 and extends between the
20 sun blocker panel 2700 and the solar array axle 2701. The inner articulated portions 2704, 2705 and the outer articulated portions 2708, 2709 are sprung at hinge points 2706 and 2707 so as to automatically extend the articulated arms 2704, 2708 and 2705, 2709 to their full
25 extent as limited by the lanyard control. The articulated arms 2704, 2708 and 2705, 2709 thereby form a parallelogram, the shape of which may be controlled by retracting or deploying the lanyard 2712. Alternatively the shape of the parallelogram could be controlled by
30 motorized hinges, or alternatively by a retractable and deployable lanyard between hinge points 2706 and 2707 with sprung hinges 2702, 2703, 2710 and 2711 instead of

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at 2706 and 2707. In the embodiment of the invention illustrated in FIGURES 21 through 24, the distance of the sun blocker panel 2700 from the solar array boom 2701 can be varied as the sun blocker panel 2700 rotates about the solar array boom 2701 to maintain the sun blocker panel at a constant distance from the spacecraft as illustrated by the path 2712.

The embodiments described in FIGURES 18 through 20 have the advantage that the attachment arm does not obscure thrusters 1810 present on the face of the spacecraft, that the sun blocker panel shades.

A sun blocker panel 3100, 3200 is not necessarily rectangular in shape. As shown in FIGURE 31, the sun blocker panel 3100 has trapezoidal first-and second-extensions 3101, 3102 hingedly attached to a main body 3103 of a sun blocker panel 3100. The first extension 3101 is extended by unfolding the extension through rotation in the direction of the arrows 3104 and the second extension is extended by unfolding the extension through rotation in the direction of the arrows 3105 from a position flat against the main body 3103.

As shown in FIGURE 32 a rectangular main body 3202 of the sun blocker panel 3200 may have substantially triangular extensions 3201, 3202 which may be extended and retracted from the main body by sliding translation of the extension 3201 in the direction of double-handed arrow 3204 and unfolding the extension 3202 in the direction of arrows 3205.

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The descriptions of designs for the structural support and the deployment of sun ray blocker devices written herein are examples from thousands of possible structural support and deployment designs which can be used for this purpose and are within the scope of the present invention.

This paragraph describes an example to demonstrate the geometrical approach to calculating the dimensions of a sun blocker panel for providing total shadow coverage to a quasi-rectangular shaped radiator surface. The example used is that of a radiator surface on a north or south panel of a geostationary spacecraft, like the previously defined "model" spacecraft for example, at the summer or winter solstice, when the incidence angle of the Sun's rays (measured from the plane of the benefited thermal radiator surface) is at a maximum, using a quasi-rectangular (for this simple illustration at least) shaped sun blocker panel whose plane is perpendicular to the plane of the associated thermal radiator surface (referring to FIGURE 12a, angle 501 is then 90 degree). For this example, take the north or south radiator-surface of the spacecraft to be rectangular, of length and width A and B, respectively. Then, the length and width dimensions, L and W, respectively, of the sun-exposed surface of the fully-deployed sun blocker panel (which is shown in FIGURES 16a and 17a) should be as follows: L is greater than or equal to $\sqrt{A^2+B^2}$, and W is greater than or equal to $0.435 \times \sqrt{A^2+B^2}$ based on the corresponding orbit-sun angle of 23.5 degree. However, if only a portion of the surface area on the north or south panel needs to be shadowed, i.e. high heat-dissipating

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equipments were to be mounted in certain localized areas of the north or south panel, the sun ray blocker device can be tailored to shade only those areas and may accordingly be smaller. In addition, if a sun blocker panel whose plane is not perpendicular to the plane of the associated thermal radiator surface were to be selected by the spacecraft designer, the minimum value of the width, W , may be greater or less than $0.435 \times \sqrt{A^2 + B^2}$ depending on the size of angle 501 in FIGURE 12a. If angle 501 is greater than 90 degree, W may be greater than $0.435 \times \sqrt{A^2 + B^2}$; if it is less than 90 degree, W may be less than $0.435 \times \sqrt{A^2 + B^2}$. If additional shading to the other four panels, earth, zenith, east and west panels, is desired, the width (W) of the sun blocker panel can be increased to extend past the imaginary plane 250 toward the center of the satellite as shown in FIGURE 7.

Thus, by the foregoing descriptions contained herein it can be seen that by virtue of the present invention losses in the efficiency of the cooling of the thermal radiator panels of a spacecraft caused by solar heating can be eliminated or minimized via various sun blocking arrangements.

Obviously, numerous modifications to and variations on the present invention are possible in light of the above teachings. For example, as a practical matter, a designer might counterweight or counterbalance the rotating axles or arms to overcome the weight imbalance caused by sun ray blocker devices of the present invention without exceeding the scope of the present

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invention. It is therefore understood that within the scope of the appended claims, the invention may be practiced otherwise than as specifically described herein.

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CLAIMS

1. A spacecraft for orbiting a sunlit celestial body (300), the spacecraft including a thermal radiator surface (11,12,1804, 2121, 2721) for radiating heat
5 from the spacecraft into space, and a sun ray blocker device (111,112, 141, 271, 301, 411, 511, 611, 811, 921, 951,1800,2100, 2700) mounted on said spacecraft for shielding said thermal radiator surface (11,12,1804,2121,2721) from rays of sunlight,
10 characterised in that said sun ray blocker device is locatable for placing in shadow substantially the whole of the thermal radiator surface (11,12,1804,2121,2721) from sunlight without substantially impeding thermal radiation from said thermal radiator surface
15 (11,12,1804,2121,2721) into space.
2. A spacecraft as claimed in claim 1, wherein an effective radiation view factor for thermal radiation from the thermal radiator surface (11,12,1804, 2121,2721) to deep space is significantly greater than
20 a corresponding geometrical radiation view factor to deep space, and in particular, for a geostationary spacecraft where the geometrical radiation view factor to deep space is 0.65, the effective radiation view factor to deep space is at least 0.87.
- 25 3. A spacecraft as claimed in claims 1 or 2, wherein the sun ray blocker device includes at least one sun blocker panel (111, 112) having a sun-facing surface (111a, 112a) and an opposed anti-sun-facing surface (111b, 112b), wherein the sun-facing surface (111a,

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112a) is thermally insulated from the opposed surface (111b, 112b).

4. A spacecraft as claimed in claim 3, wherein the sun-facing surface (111a, 112a) is thermally insulated from the opposed surface (111b, 112b) by a multi-layer insulation blanket.
5. A spacecraft as claimed in claims 3 or 4, wherein the sun-facing surface (111a, 112a) has a low solar energy absorptivity of less than 0.5.
- 10 6. A spacecraft as claimed in any of claims 3 to 5, wherein the sun-facing surface (111a, 112a) includes a solar cell panel for supplying electrical power to the spacecraft.
7. A spacecraft as claimed in any of claims 3 to 6, wherein the sun-facing surface (111a, 112a) has a high thermal emissivity of higher than 0.7.
- 15 8. A spacecraft as claimed in any of claims 3 to 7, wherein the sun ray blocker device (111, 112, 141, 271, 301, 411, 511, 611, 811, 921, 951, 1800, 2100, 2700) is moveable between a stowed, non-operative position and a deployed operative position.
- 20 9. A spacecraft as claimed in any claims 3 to 8, wherein the sun ray blocker device (111, 112, 141, 271, 301, 411, 511, 611, 811, 921, 951, 1800, 2100, 2700) includes an attachment arm (207, 205, 430, 230) for attaching the sun blocker panel (111, 112) to the spacecraft.
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10. A spacecraft as claimed in claim 9, wherein the attachment arm (207, 205, 430, 230) is attached by a hinge means(406, 306) to the sun blocker panel (111, 112) and/or by a second hinge means(407, 507, 607, 307) to the spacecraft.
11. A spacecraft as claimed in any of claims 8 to 10, wherein the sun ray blocker device (111,112; 141; 271; 301; 411; 511; 611; 811; 921; 951) includes a motor for moving the sun ray blocker device (111,112; 141; 271; 301; 411; 511; 611; 811; 921; 951) between the stowed position and the deployed position.
12. A spacecraft as claimed in any of claims 3 to 11, wherein locating means are provided for locating the sun ray blocker device (111,112; 141; 271; 301; 411; 511; 611; 811; 921; 951) with respect to the thermal radiator surface (11,12) which includes adjustment means to maintain the majority of the thermal radiator surface (11,12) in shadow irrespective of changes in the attitude and/or orbit of the spacecraft during normal operations.
13. A spacecraft as claimed in claim 12, wherein the adjustment means includes a variable length attachment arm (2130, 2730)for attachment of the sun blocker panel to the spacecraft.
14. A spacecraft as claimed in claim 13, wherein the attachment arm is a scissor arm (2730).
15. A spacecraft as claimed in claim 13, wherein the attachment arm (2130)is formed of articulated portions (2132, 2134, 2137) which may be mutually articulated

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15. A spacecraft as claimed in claim 13, wherein the transport means includes rail means (2002) and belt means (2003) connected to the carriage means (2001), the belt means being driven by drive means (2030) to
5 move the carriage means along the rail means (2002).

16. A spacecraft as claimed in claim 13, wherein the carriage means includes an annulus (1920) rotatable in a circular path defined by bearing means (1903) the annulus being driveable by drive means (1930) to move
10 the carriage along the path defined by the bearing means.

17. A spacecraft as claimed in any of claims 12 to 16, having a solar cell array (100, 101, 408) adapted for tracking movements of the Sun relative to the
15 spacecraft, wherein the adjustment of the location of the sun ray blocker device (111, 112, 141, 271, 301, 411, 511, 611, 811, 921, 951) in relation to the thermal radiator surface (11, 12, 1804, 2121, 2721) is synchronised with the tracking movement of the solar
20 cell array, when in normal operation.

18. A spacecraft as claimed in claim 17, wherein the sun ray blocker device (111, 112; 141; 271; 301; 411; 511; 611; 811; 921; 951) is mounted on the solar cell array (100, 101 408) or on means carrying said solar cell
25 array.

19. A spacecraft as claimed in claim 18, wherein the solar cell array tracks the movement of the Sun by rotation of the solar cell array about an axis of rotation of the solar cell array (100, 101, 408) such

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that the sun blocker panel (111, 112) also rotates about said axis of rotation of the solar cell array.

20. A spacecraft as claimed in claim 19, wherein the thermal radiator surface (11, 12) is orthogonal to the axis of rotation of the solar cell array so that the sun blocker panel (111, 112) rotates about an axis normal to the thermal radiator surface.
21. A spacecraft as claimed in claim 18-20, wherein the adjustment means includes a variable length attachment arm (2130, 2730) for attachment of the sun blocker panel to the spacecraft.
22. A spacecraft as claimed in claim 21, wherein the attachment arm is a scissor arm (2730).
23. A spacecraft as claimed in claim 21, wherein the attachment arm (2130) is formed of articulated portions (2132, 2134, 2137) which may be mutually articulated during rotation to vary an effective length of the attachment arm.
24. A spacecraft as claimed in any of claims 21-23, wherein the adjustment means for attachment of the sun blocker panel (2100, 2700) to a solar cell array assembly (2131, 2701) are such that a distance between the sun blocker panel from the solar cell array assembly (2130, 2730) may be varied during rotation of the sun blocker panel.
25. A spacecraft as claimed in any of claims 3 to 24, wherein means (929, 931, 955, 957) are provided for adjusting the size of the sun blocker panel (111, 112).

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26. A spacecraft as claimed in any of the preceding claims, including control means for controlling the spacecraft so as to maintain an angle between a sun line and the thermal radiator surface (11,12) below a predetermined angle by adjustment of the orbit and/or attitude of the spacecraft in use.
27. A spacecraft as claimed in claim 26, wherein the predetermined angle is 60 degrees.
28. A spacecraft as claimed in claims 26 or 27, wherein the control means is adapted to maintain the thermal radiator surface (11,12) substantially parallel to a plane of an orbit of the spacecraft.
29. A spacecraft as claimed in any of claims 26 to 28, wherein the control means is adapted to maintain the spacecraft in a sun synchronous orbit.
30. A spacecraft as claimed in any of claims 26 to 28, wherein the control means is adapted to maintain the spacecraft in an equatorial or low-inclination orbit.
31. In a three axis stabilised spacecraft for orbiting about a planet and having at least one solar cell assembly having at least one solar cell panel, and being a north solar cell panel assembly or a south solar cell panel assembly, said at least one solar cell panel assembly being mounted on an axle so as to be controllably rotated from said spacecraft about an axis of rotation so as to face the Sun, said spacecraft having a nadir panel which is generally pointing to the centre of the planet, an opposite panel known as a zenith panel, which faces away from the centre of the

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planet and sharing the same planar normal vector as said nadir panel, an east panel and a west panel, said east panel and said west panel having their planar normal vector laying on a orbital plane pointing to the velocity vector of the spacecraft generally tangential to the direction of travel on the orbit, and a north panel and a south panel, said north panel and said south panel having their planar normal vector generally perpendicular to the orbit plane and parallel to the axis of rotation of the planet, said solar cell panel extending outwardly from said spacecraft, the improvement which comprises:

attaching at least one sun ray blocker device to said at least one solar cell panel, said at least one device being either a north blocker device or being a south blocker device and corresponding to said at least one solar cell panel, each of said at least one sun ray blocker device being positioned forwardly from and offset relative to a solar cell surface of a solar cell panel and at a predetermined angle to either of said north panel and said south panel, said north panel or said south panel, said sun ray blocker device being positioned so as to cast a shadow on at least a majority of the exposed surface of its corresponding north or south panel during solar exposure thereto.

32. In a three axis stabilised low inclination orbit spacecraft for orbiting about the earth and having two sets of solar cell array assemblies having solar cell arrays, one set being a north solar array assembly and the other being a south solar array assembly, said assemblies each being mounted on an axle so as to be

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controllably rotated from said spacecraft about an axis of rotation so as to face the Sun, said spacecraft having an earth panel which is generally pointing to the centre of the earth, an opposite panel known as a zenith panel, which faces away from the centre of the earth and sharing the same planar normal vector as said earth panel, an east panel and a west panel, said east panel and said west panel having their planar normal vector laying on an orbital plane pointing to the velocity vector of the spacecraft generally tangential to the direction of travel on the orbit, and a north panel and a south panel, said north panel and said south panel having their planar normal vector generally perpendicular to the orbit plane and parallel to the axis of rotation of the earth, said solar cell panel extending outwardly from said spacecraft, the improvement which comprises:

attaching at least one sun ray blocker device to each of said north solar array and said south solar array, one device being a north device and another device being a south device, each of said sun ray blocker devices being in the form of a panel and being positioned forwardly and offset relative to the solar cell surface of a solar ray and at a predetermined angle to said north panel and said south panel, said north blocker device being positioned so as to cast a shadow on at least a majority of the exposed surface of said north panel during solar exposure thereto, and said south blocker device being positioned so as to cast a shadow on the exposed surface of said south panel during solar exposure thereto.

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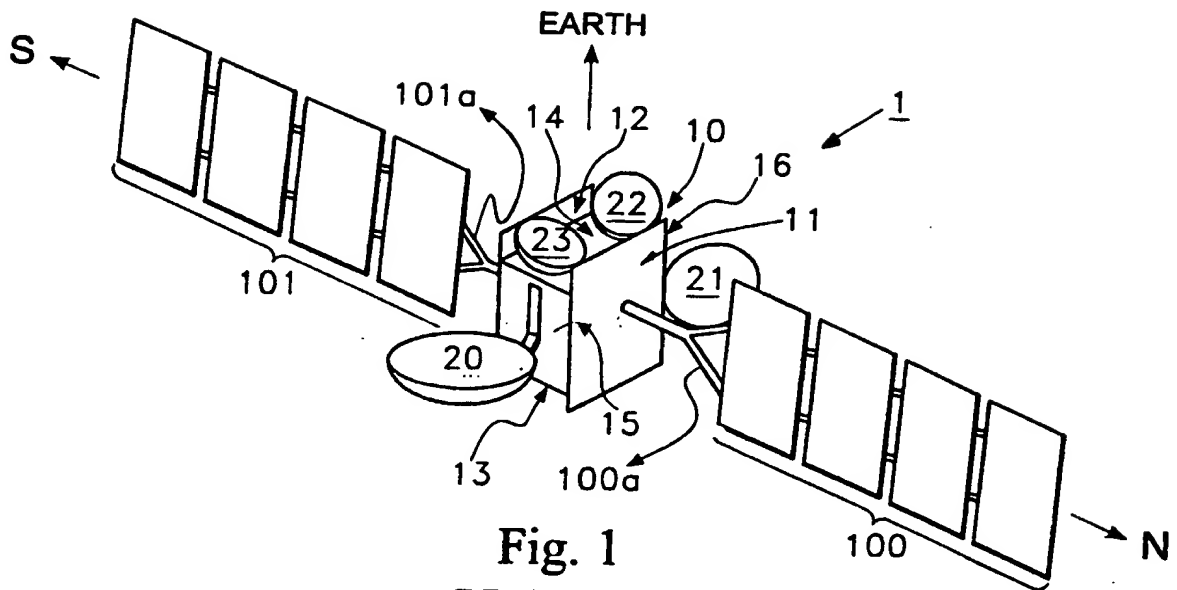


Fig. 1
PRIOR ART

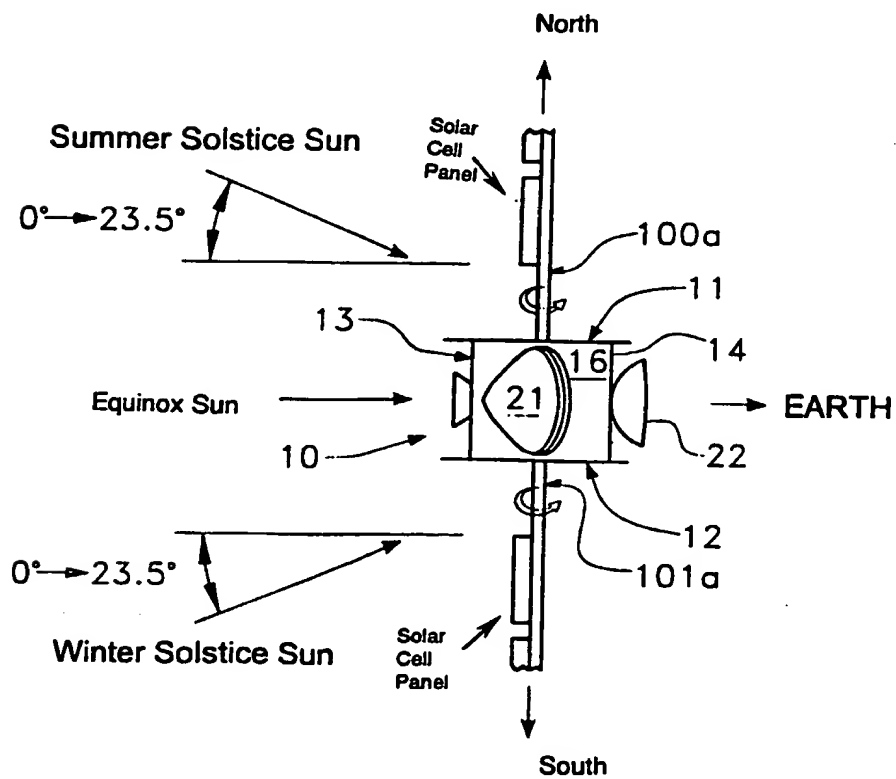


Fig. 2
PRIOR ART

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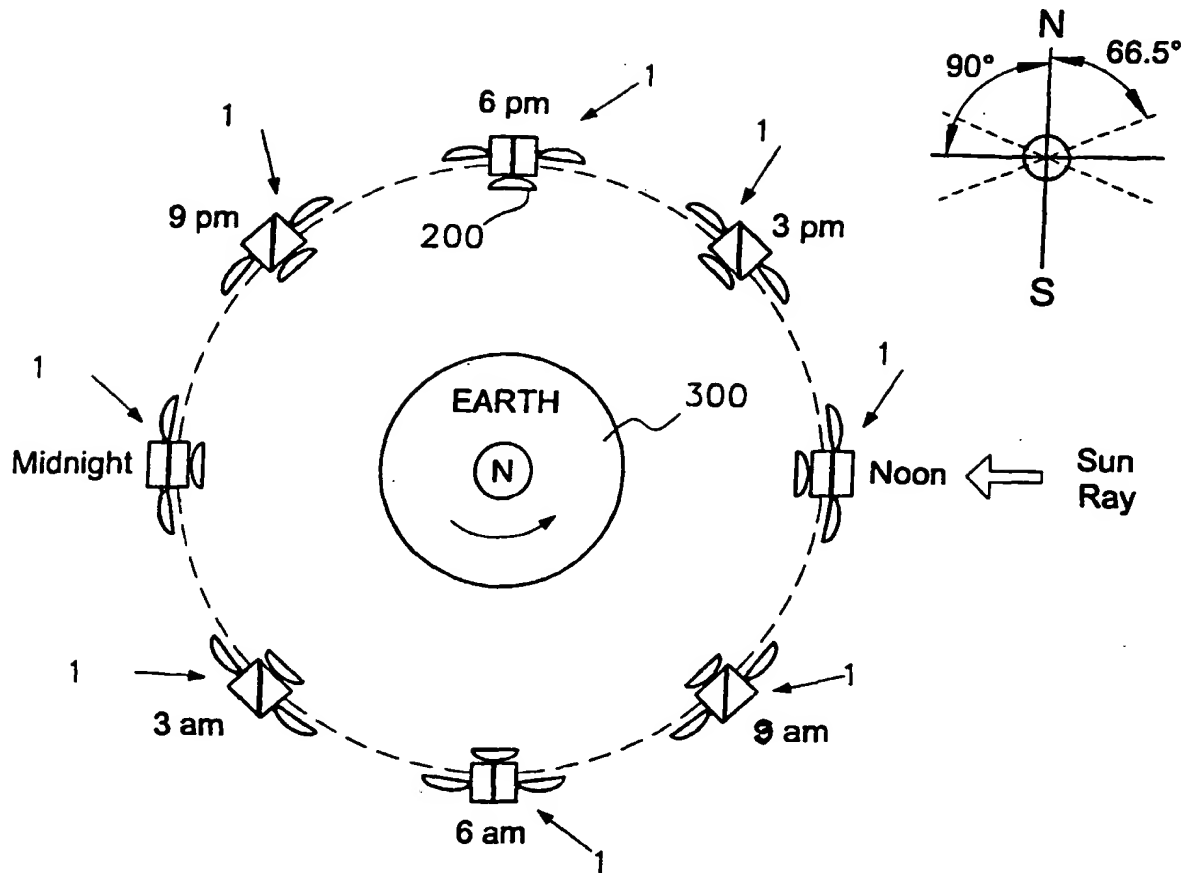


Fig. 3a
PRIOR ART

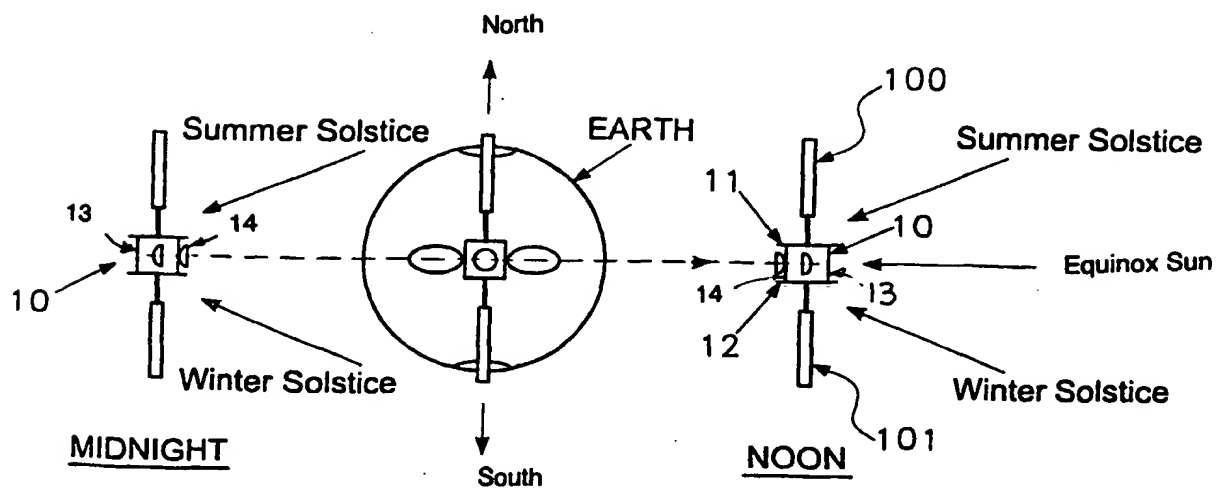


Fig. 3b
PRIOR ART

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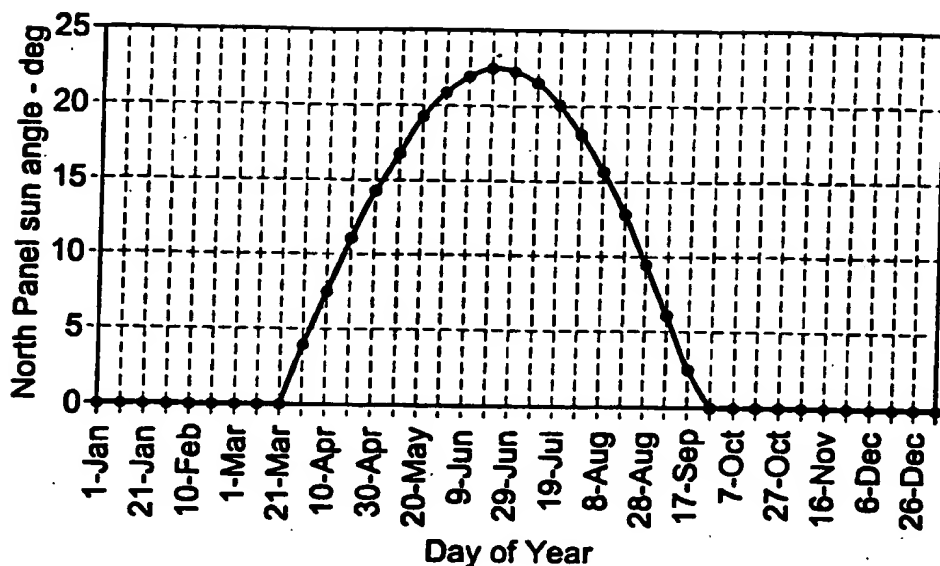


Fig. 4a

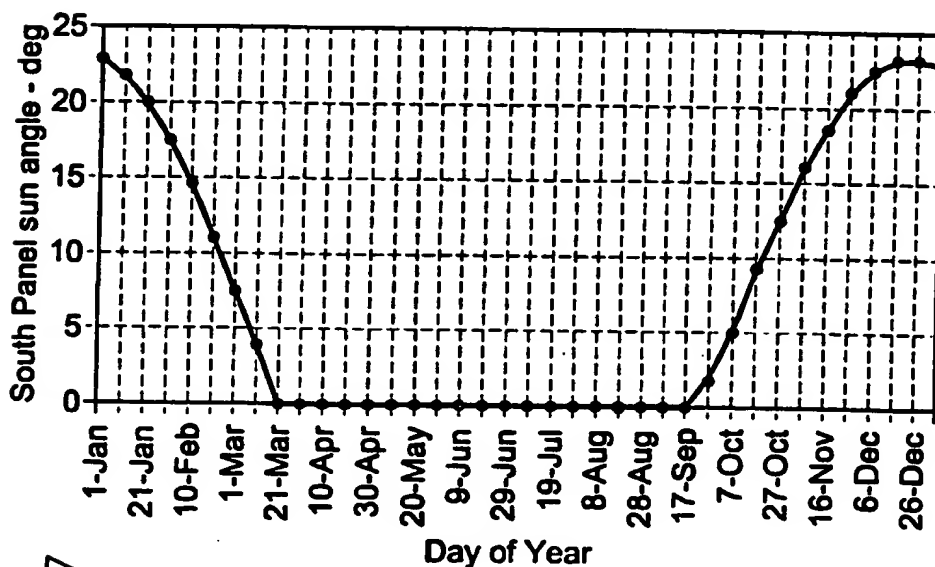


Fig. 4b

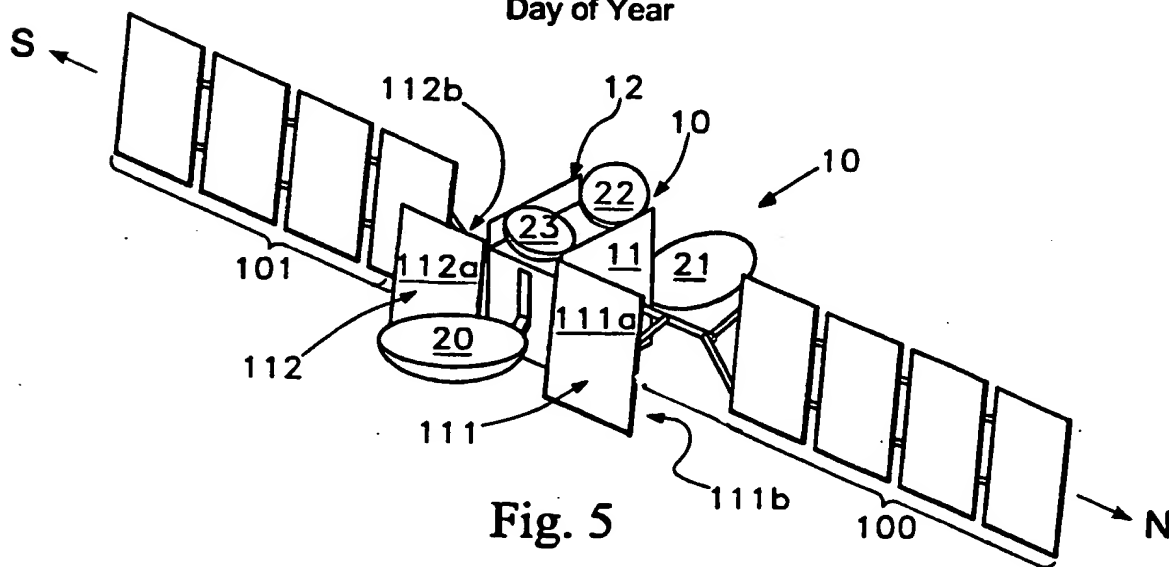


Fig. 5

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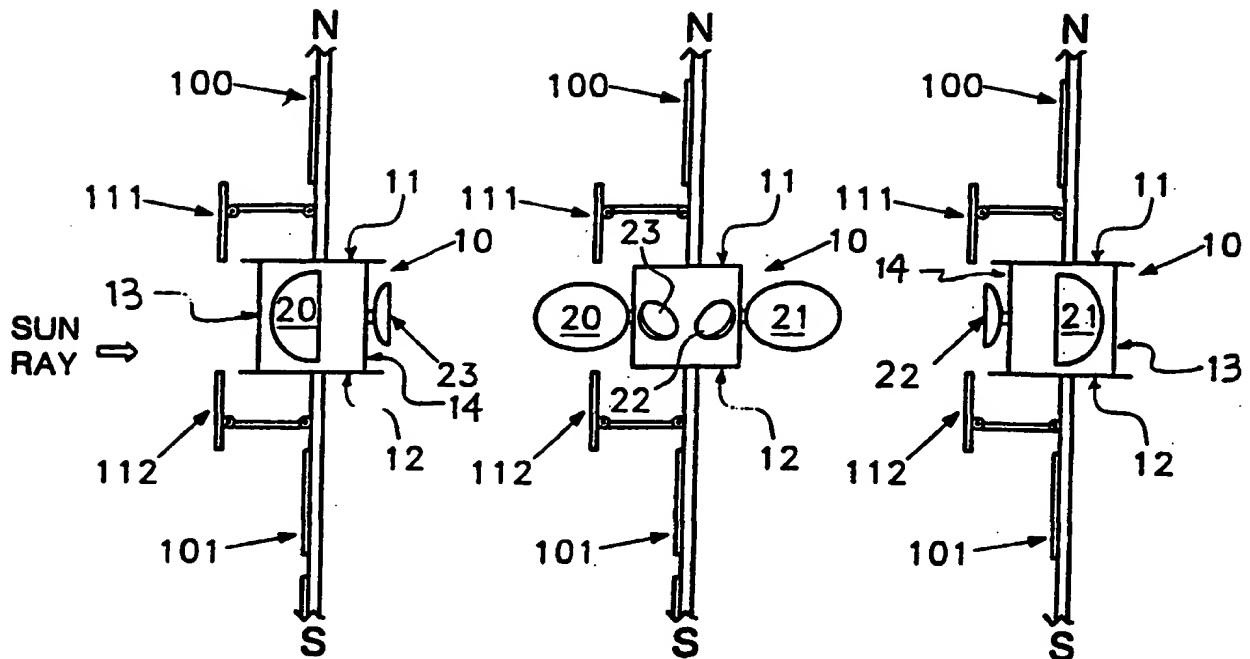


Fig. 6a

Fig. 6b

Fig. 6c

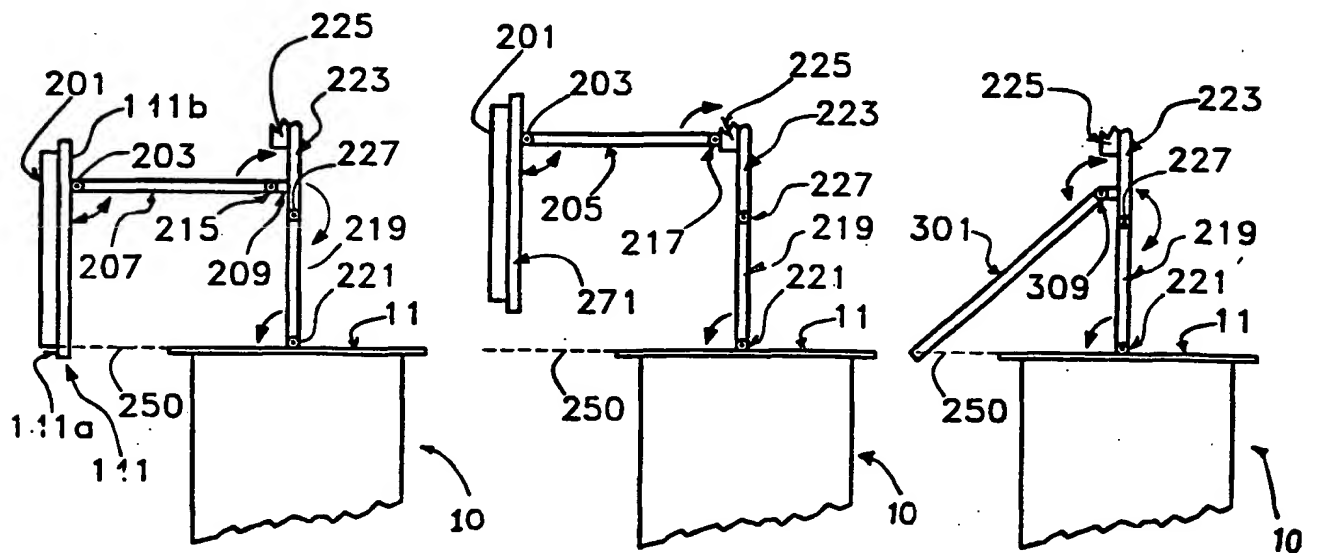
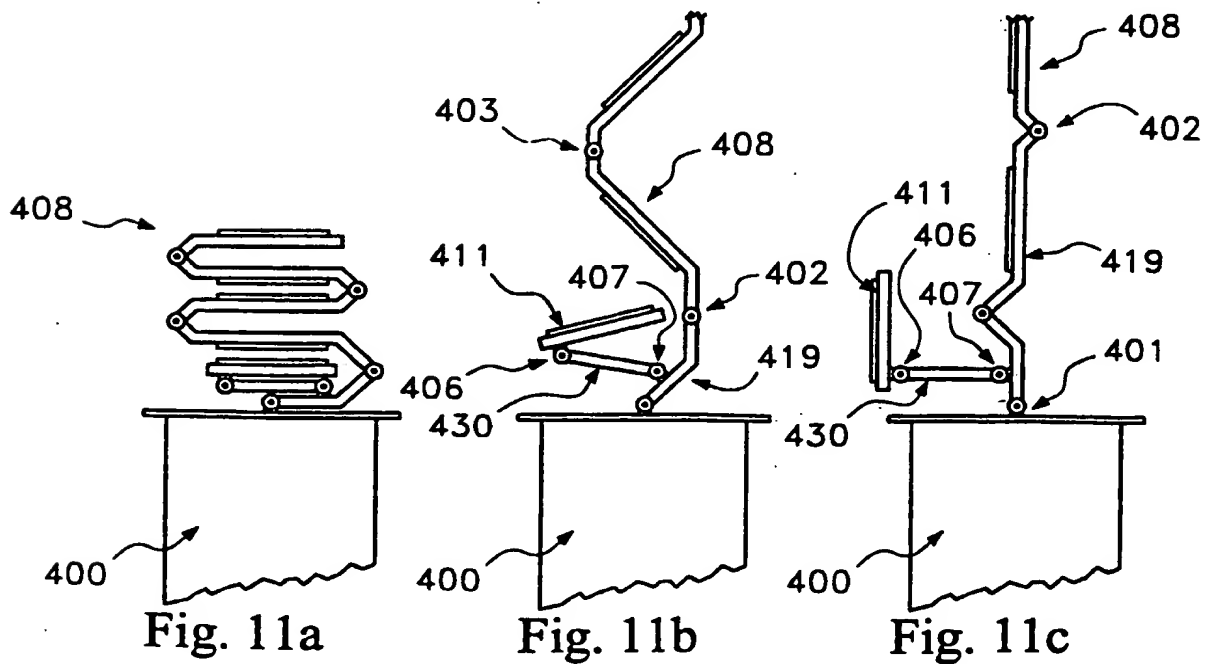
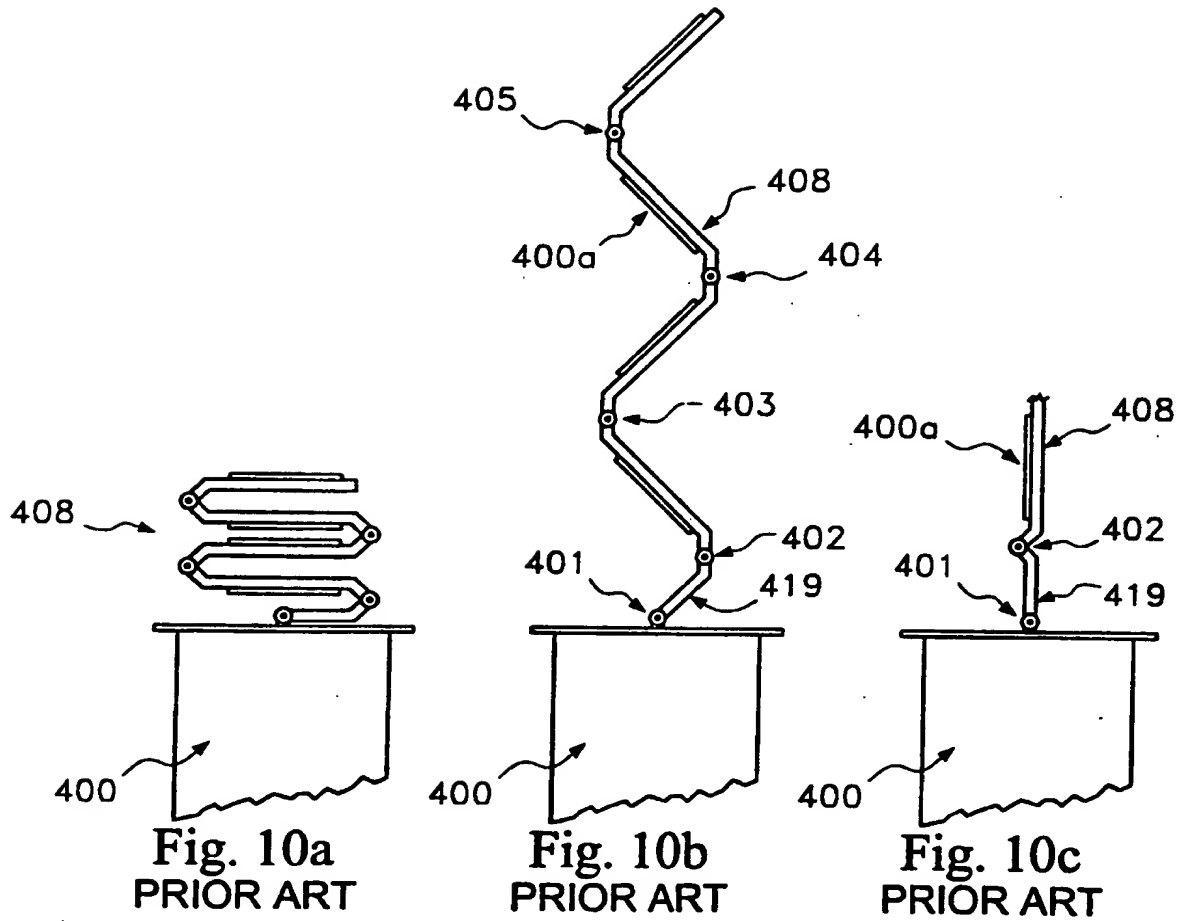


Fig. 7

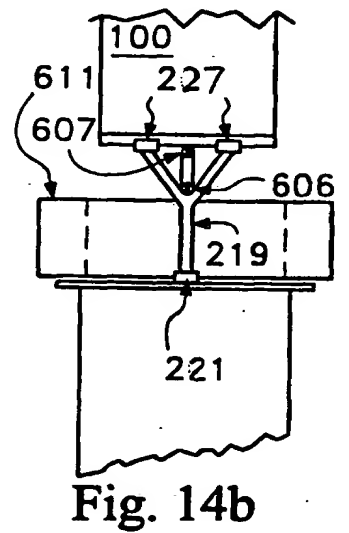
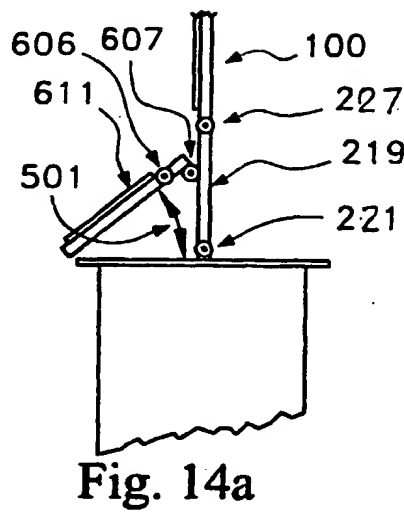
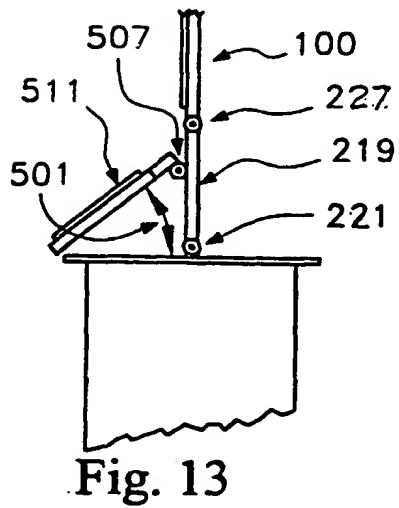
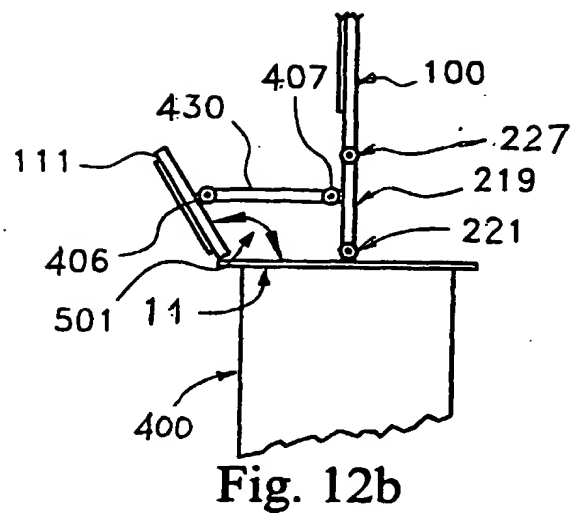
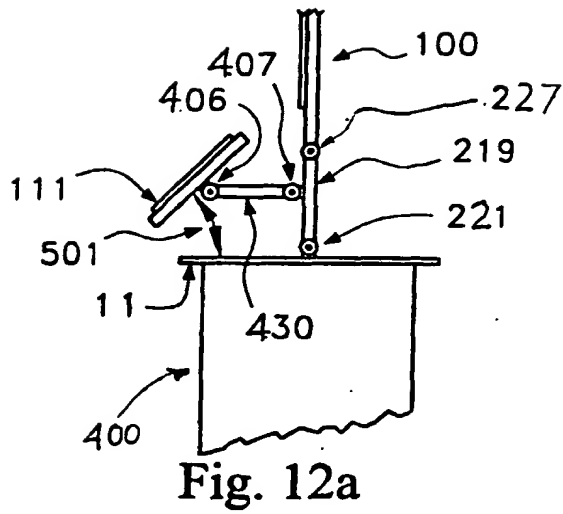
Fig. 8

Fig. 9

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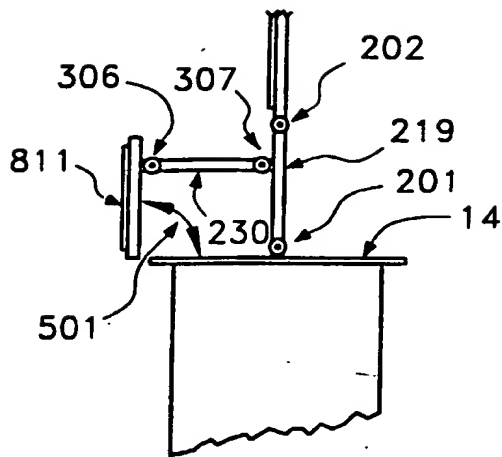


Fig. 15a

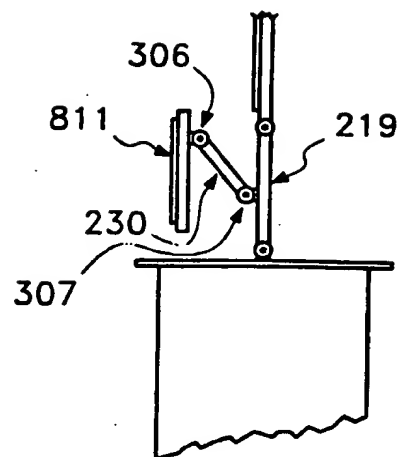


Fig. 15b



Fig. 16a

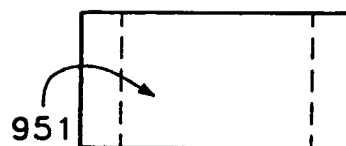


Fig. 17a

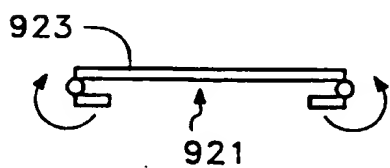


Fig. 16b

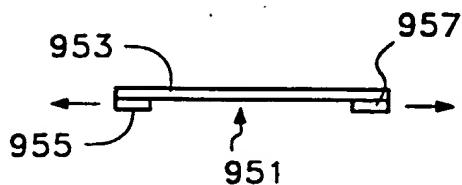


Fig. 17b

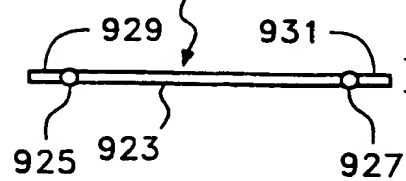


Fig. 16c

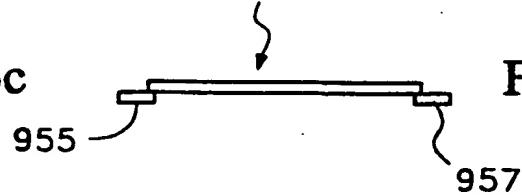


Fig. 17c

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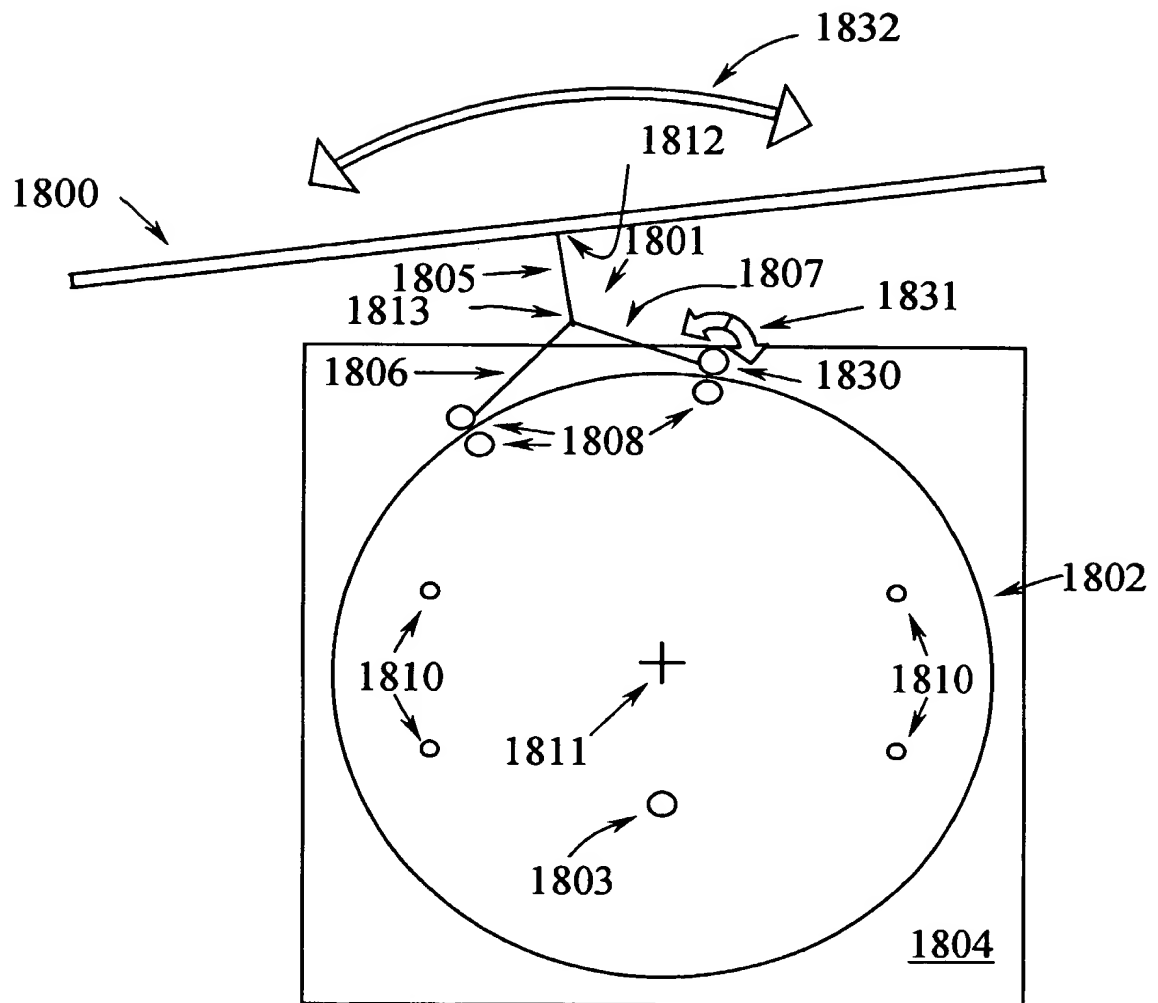


Fig. 18

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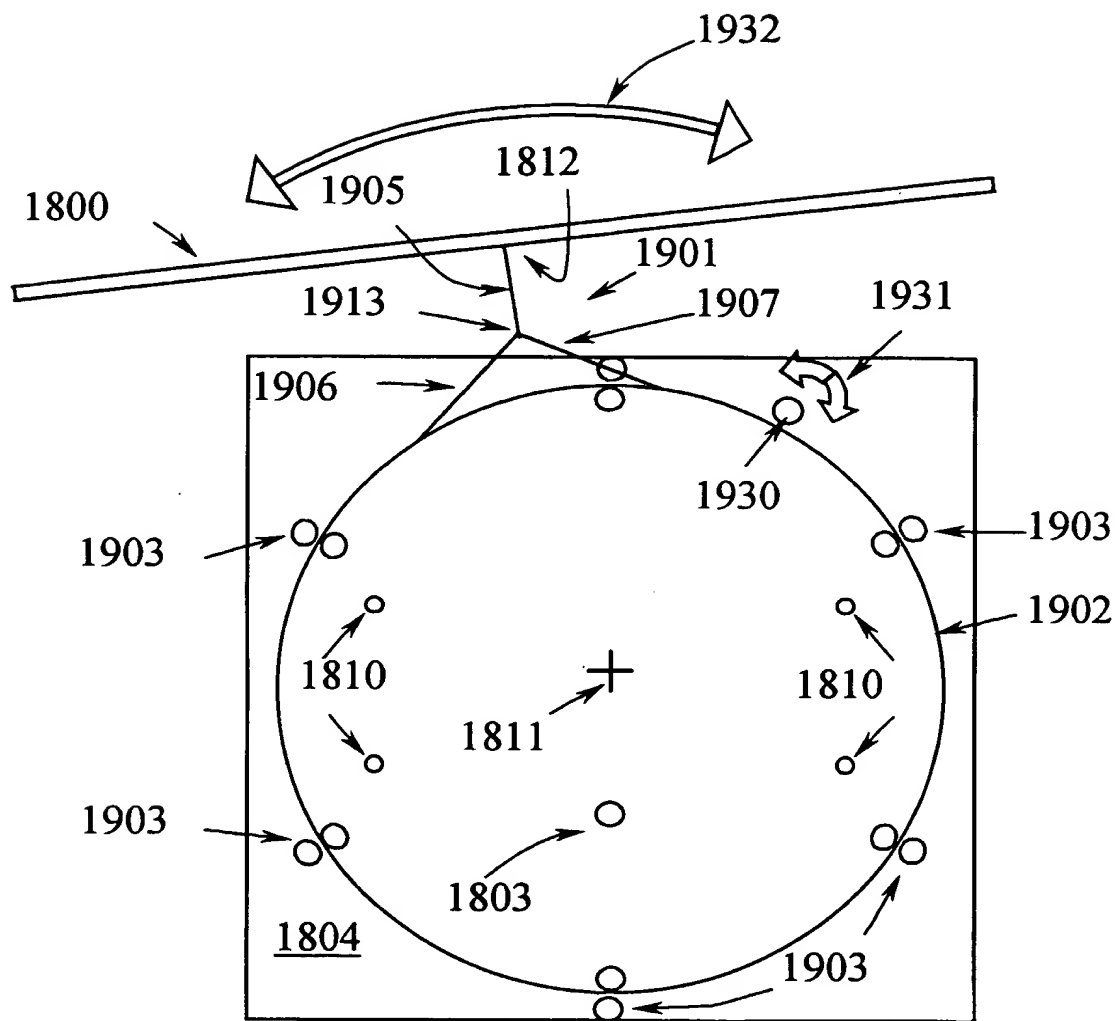


Fig. 19

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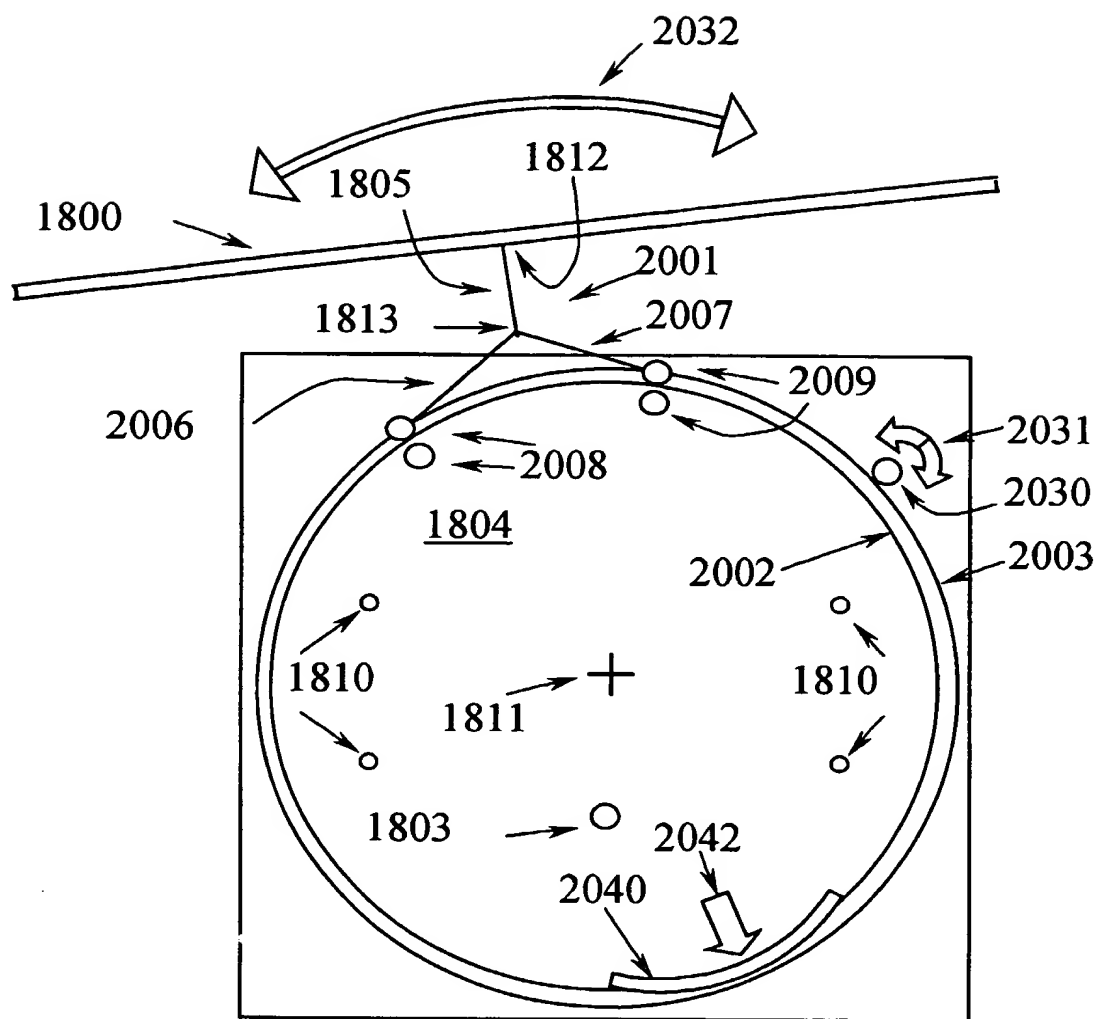


Fig. 20

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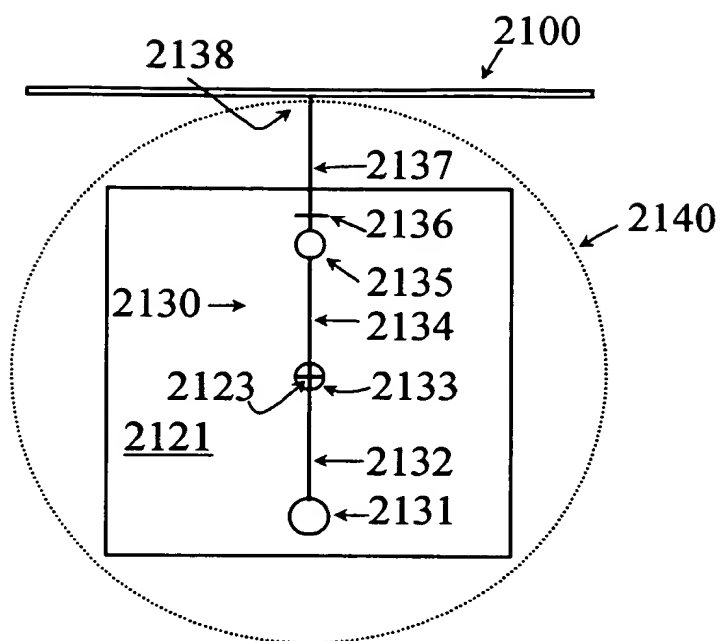


Fig. 21

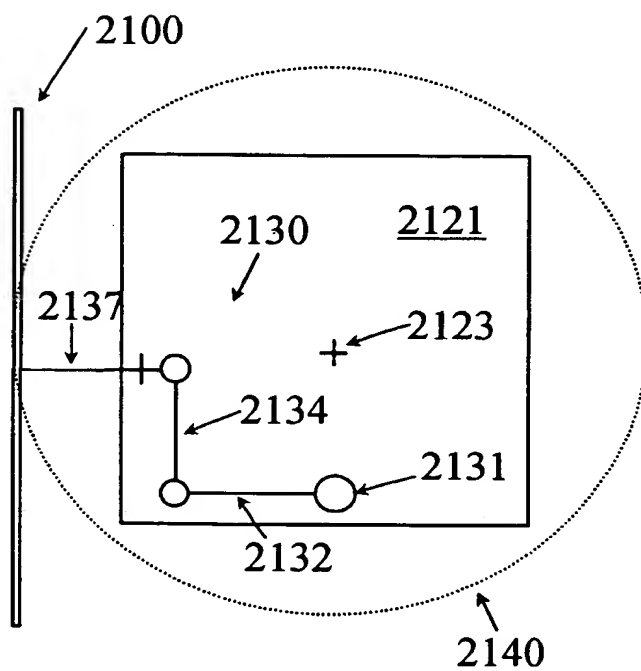


Fig. 22

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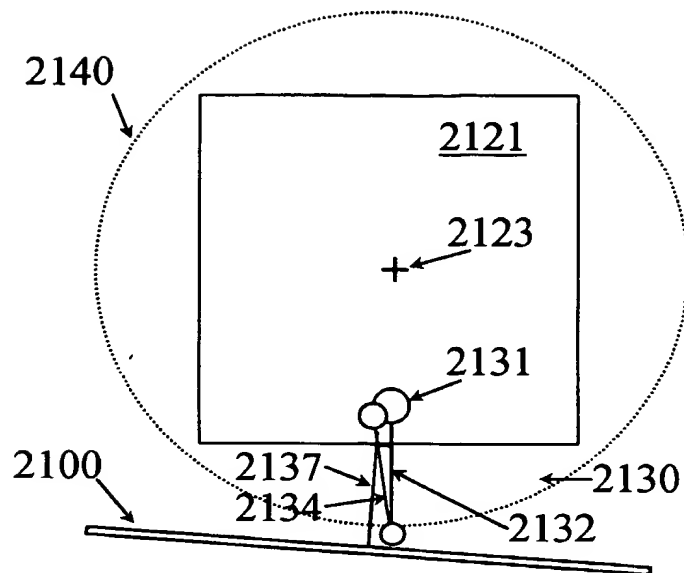


Fig. 23

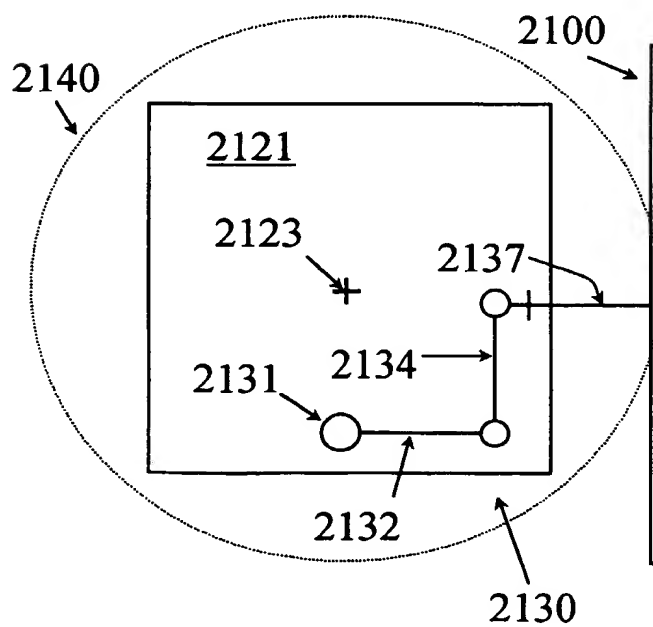


Fig. 24

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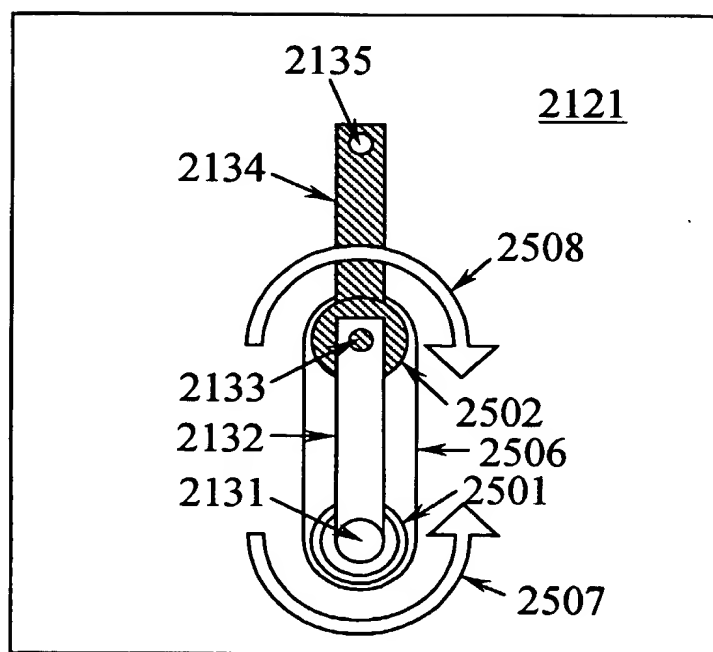


Fig. 25

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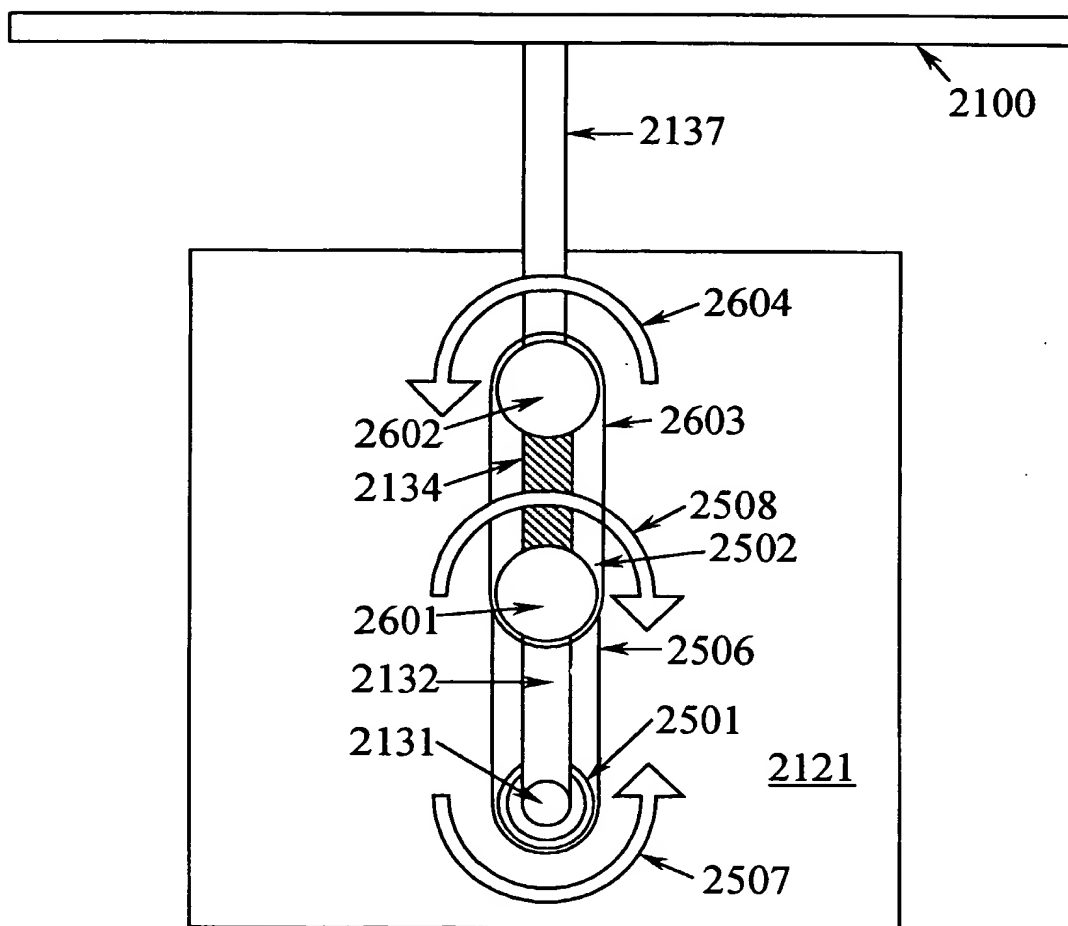


Fig. 26

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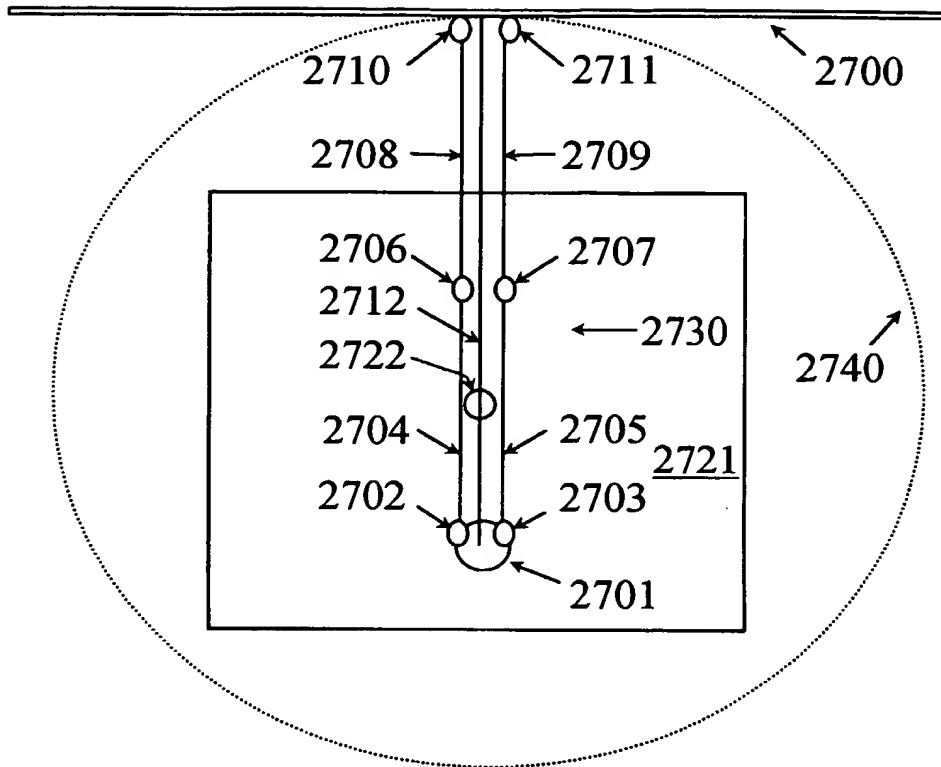
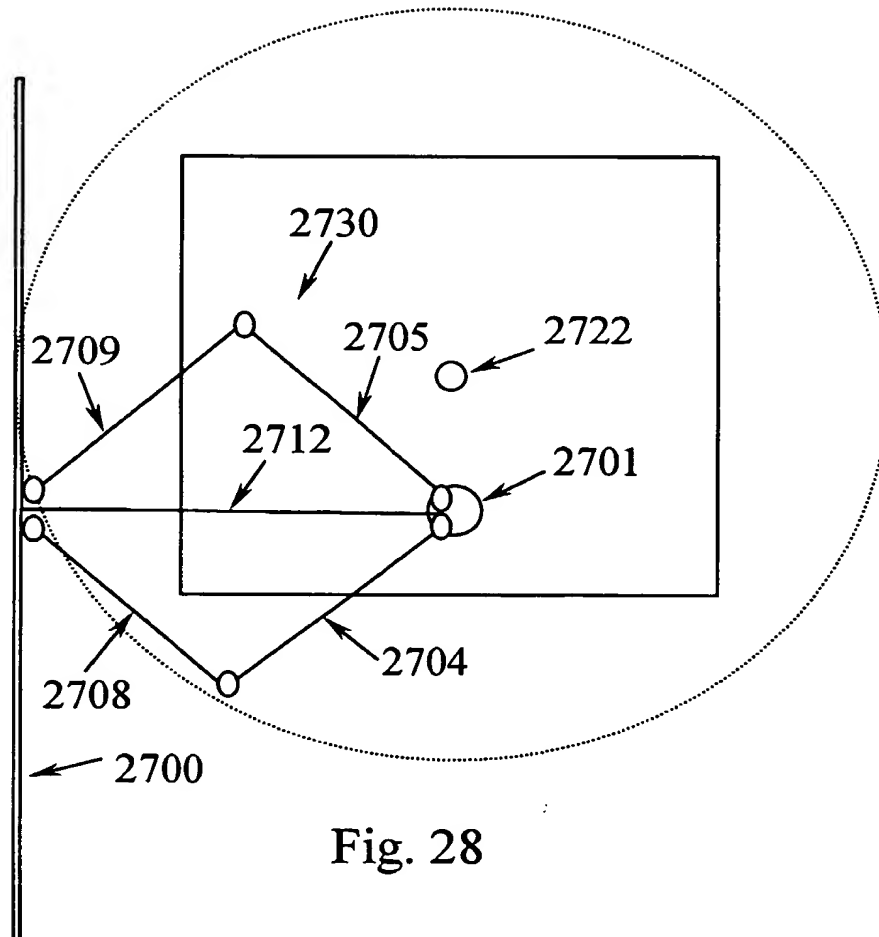


Fig. 27

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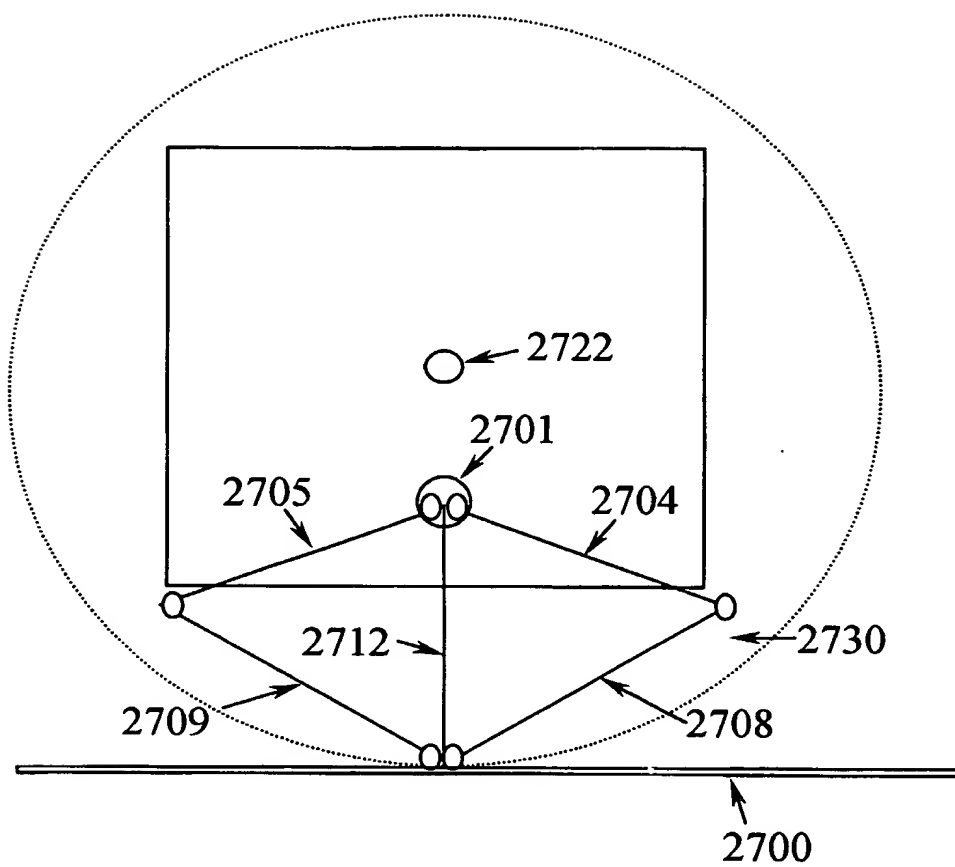


Fig. 29

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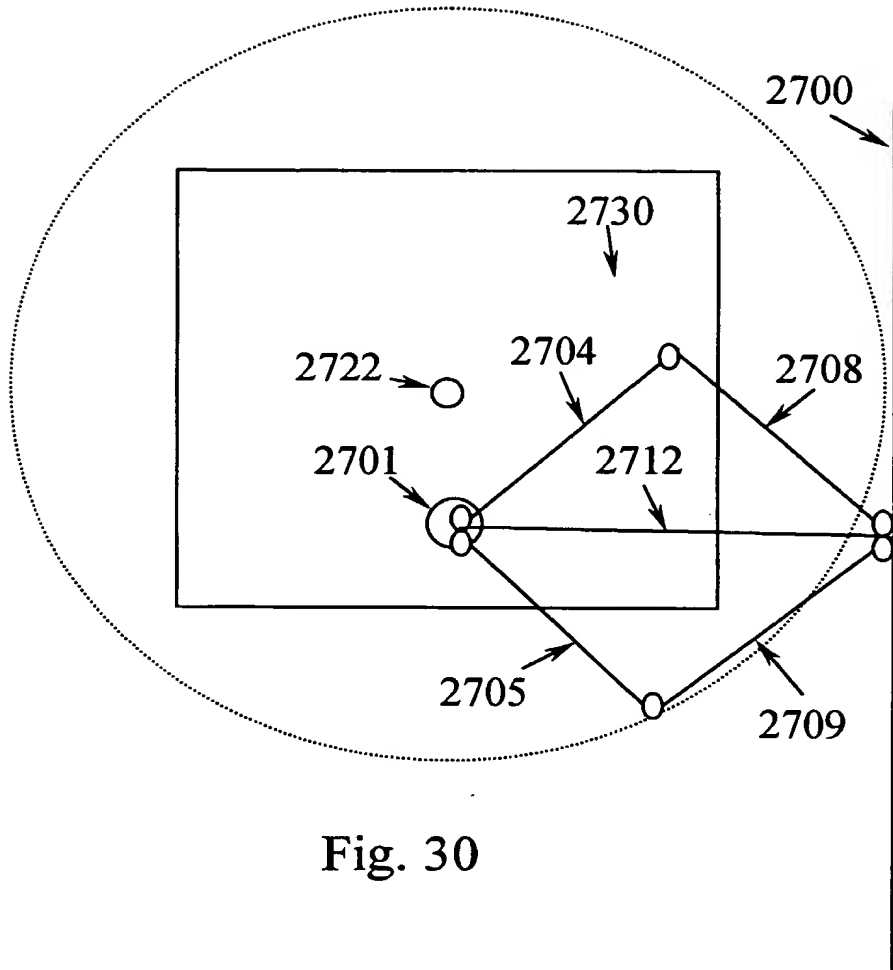


Fig. 30

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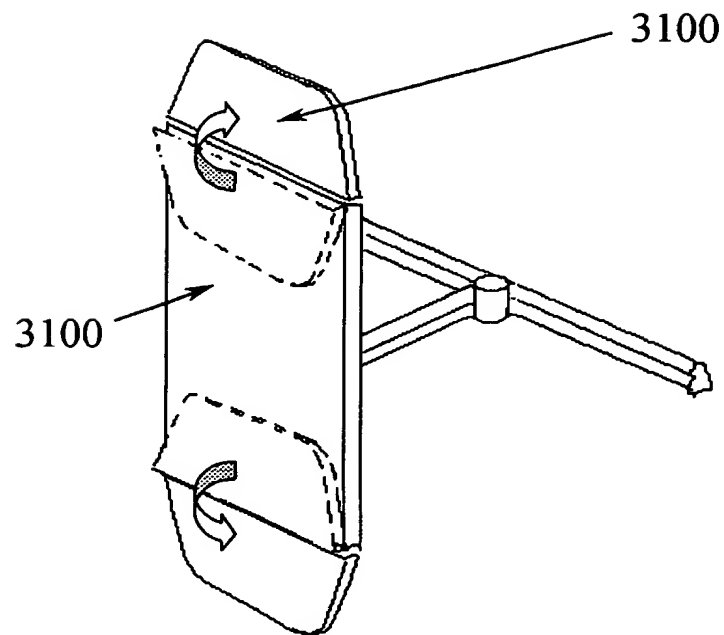


Fig. 31

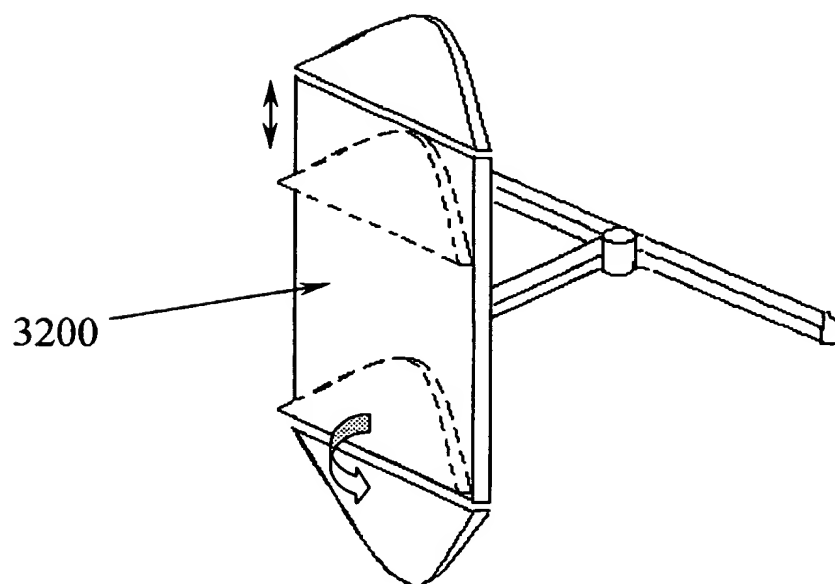


Fig 32

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 99/08572

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 B64G1/50

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 6 B64G

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
P, X	EP 0 887 260 A (AEROSPATIALE) 30 December 1998 (1998-12-30) the whole document	1-5, 7-12, 17-20, 26-28, 30-32
X	EP 0 447 049 A (MARCONI GEC LTD) 18 September 1991 (1991-09-18) the whole document	1-12, 17-20, 25-28, 30 31, 32
X	EP 0 271 370 A (CENTRE NAT ETD SPATIALES) 15 June 1988 (1988-06-15) the whole document	1-5, 7, 12, 17, 26-28, 30
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Date of the actual completion of the international search

25 February 2000

Date of mailing of the international search report

15/03/2000

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INTERNATIONAL SEARCH REPORT

Int'l Application No
PCT/US 99/08572

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X A	US 5 527 001 A (STUART JAMES R) 18 June 1996 (1996-06-18) abstract column 6, line 17 - line 55	1,2 3,6, 8-13,15, 17-21,23
A	US 4 725 023 A (SHIKI HARUO) 16 February 1988 (1988-02-16) cited in the application column 1, line 33 - line 52 column 3, line 15 - line 40	1-3,9, 12,17-19
A	FORTESCUE P W, STARK J P W: "Spacecraft Systems Engineering" 1990, WILEY & SONS, CHICHESTER, UK XP002131587 195570 page 280, paragraph 3 -page 284, paragraph 2 table 12.5 page 288, paragraph 3 -page 291, paragraph 2 page 291, paragraph 5 -page 292, paragraph 4 page 293, paragraph 5 - paragraph 7	1-5,7

INTERNATIONAL SEARCH REPORT

 Into
 I Application No
 PCT/US 99/08572

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 0887260 A	30-12-1998	FR 2765190 A JP 11059600 A	31-12-1998 02-03-1999
EP 0447049 A	18-09-1991	JP 4218497 A	10-08-1992
EP 0271370 A	15-06-1988	FR 2605287 A AT 53360 T GR 3000547 T	22-04-1988 15-06-1990 31-07-1991
US 5527001 A	18-06-1996	AU 7139794 A WO 9429927 A	03-01-1995 22-12-1994
US 4725023 A	16-02-1988	JP 1625104 C JP 2039440 B JP 60022600 A CA 1262890 A EP 0132768 A	18-11-1991 05-09-1990 05-02-1985 14-11-1989 13-02-1985

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